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Beijing, China

A Pole-Site Small-Cell Beamforming Module For 5G mmWave and Smart City Applications

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AWR Group of NI

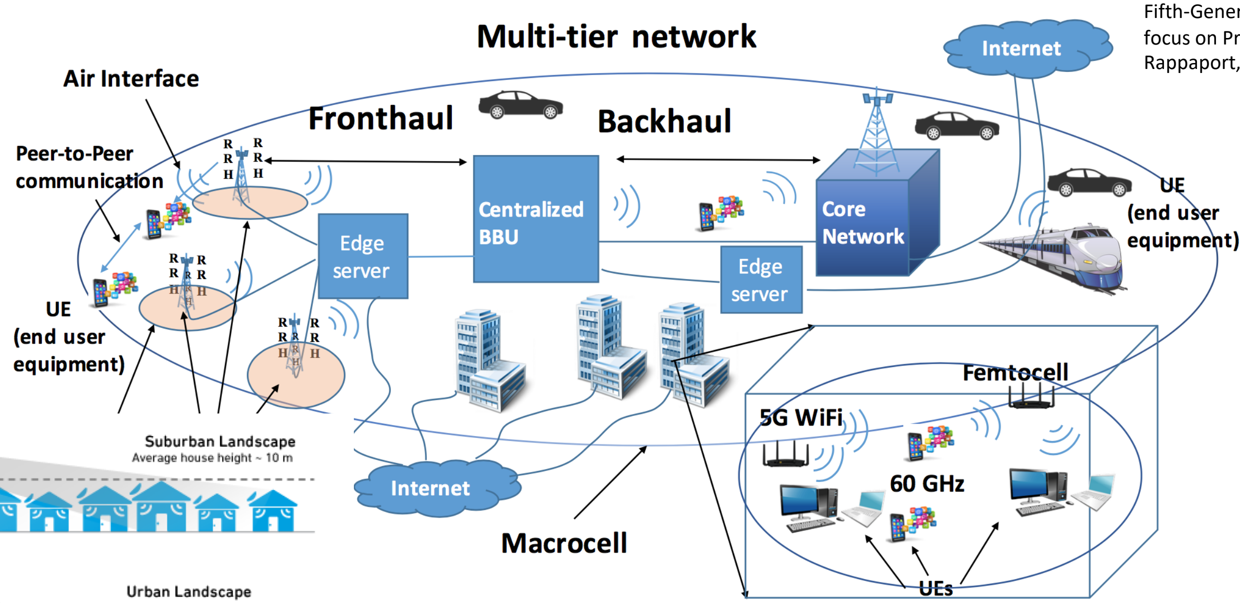
NATIONAL INSTRUMENTS™

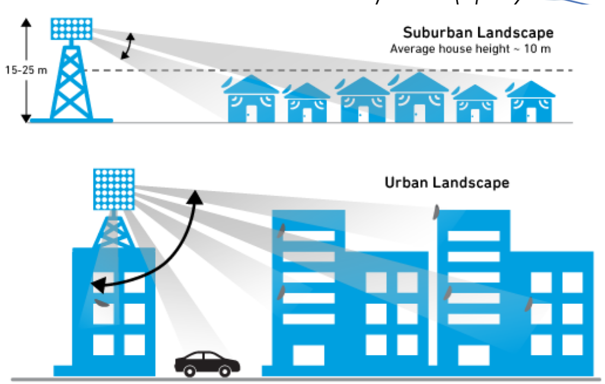
Design Goals

- Design a 28 GHz phased-array planar antenna, where each antenna is excited by a separate module
- Small Cell Phased Array Module need to cover the range and angle of street area
- The module is composed of:
  - PCB – as the motherboard, multilayer patch antennas and their feeding lines
  - SMT Module – for passive components, Beamforming and MMIC FEM module
  - SMA Connector – for RF signal to the other modules

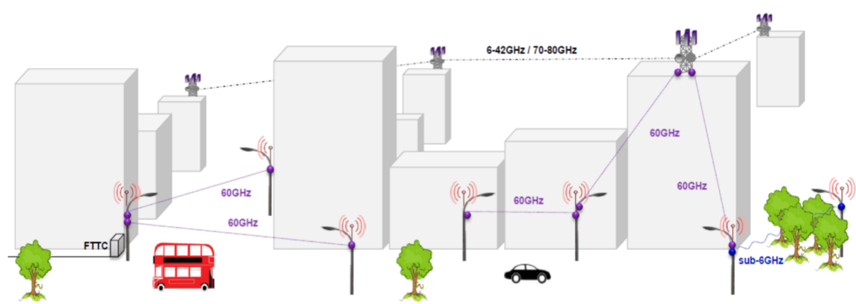
5G Scenarios

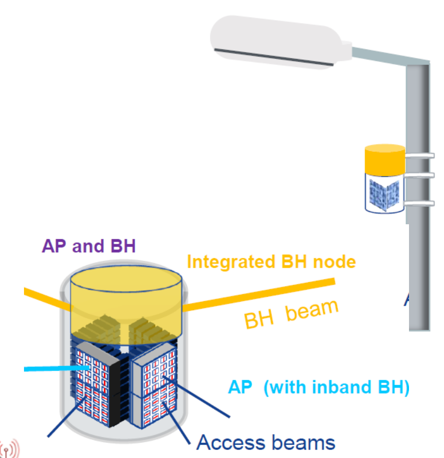
"Overview of Millimeter Wave Communications for Fifth-Generation (5G) Wireless Networks-with a focus on Propagation Models", Theodore S. Rappaport, Yunchou Xing,



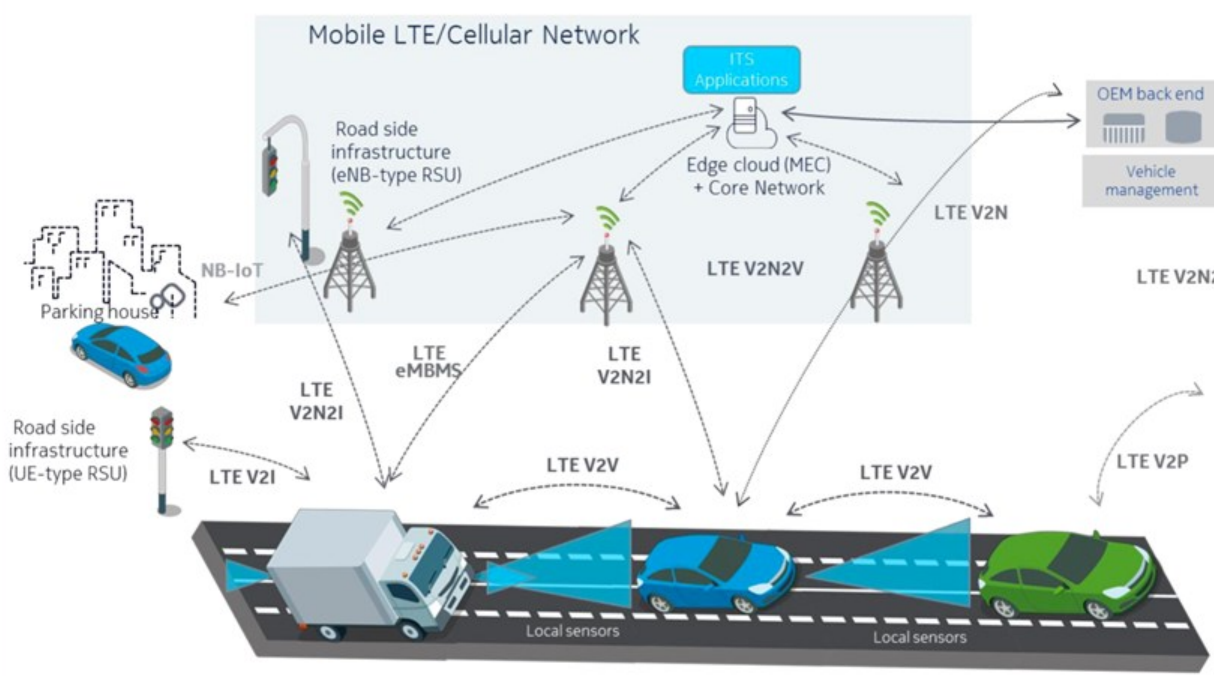


"5 Things to Consider When Designing Fixed Wireless Access (FWA) Systems", Qorvo

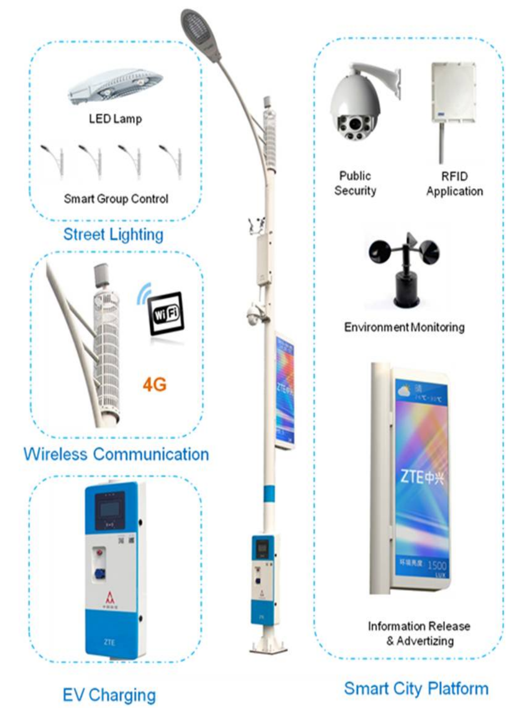


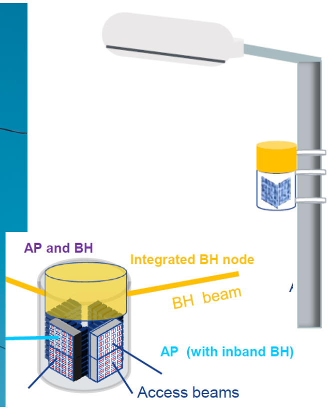


RSU for C-V2X and Smart City



From NGMN Alliance website





5G 3GPP mmWave Channel Model (WINNER II, METIS)

TABLE II
CALCULATION AND COMPARISON OF PATH LOSS.

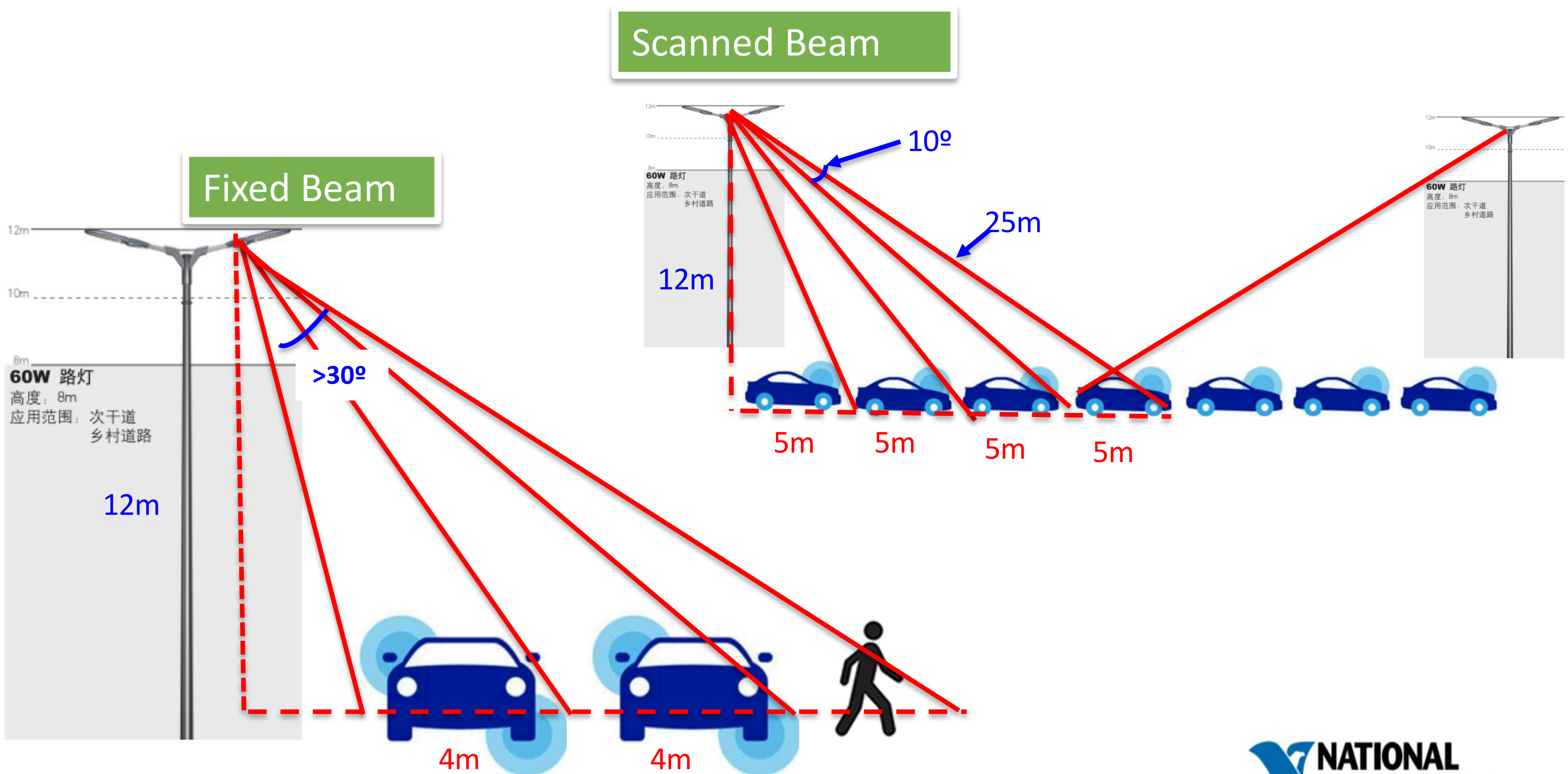
	Path loss of popular deployment scenarios (dB)					
Frequency/distance	UMa-LOS	UMa-NLOS	UMi-Street Canyon-LOS	UMi-Street Canyon-NLOS	UMi-Street Open-LOS	UMi-Street Open-NLOS
LTE Band 41 2.6 GHz, d=100m	84.8	107.5	83.4	112.7	81.9	105.6
28 GHz, d=100m	105.5	128.2	104.1	133.4	102.6	126.3
39 GHz, d=100m	108.4	131.1	107	136.3	105.5	129.2
39 GHz, d=100m, rain and oxygen loss[1]	109.4	132.1	108	137.3	106.5	139.2
LTE Band 41 2.6 GHz, d=1 km	104.9	137.5	103.2	144.6	100.4	134.5
28 GHz, d=1 km	125.5	158.2	123.9	165.3	121.1	155.2
39 GHz, d=1 km	128.4	161.1	126.8	168.2	124	158.1
39 GHz, d=1 km, rain and oxygen loss[1]	136.5	169.2	134.9	176.3	132.1	166.2

[1] Heavy rain of 25mm/h model is used

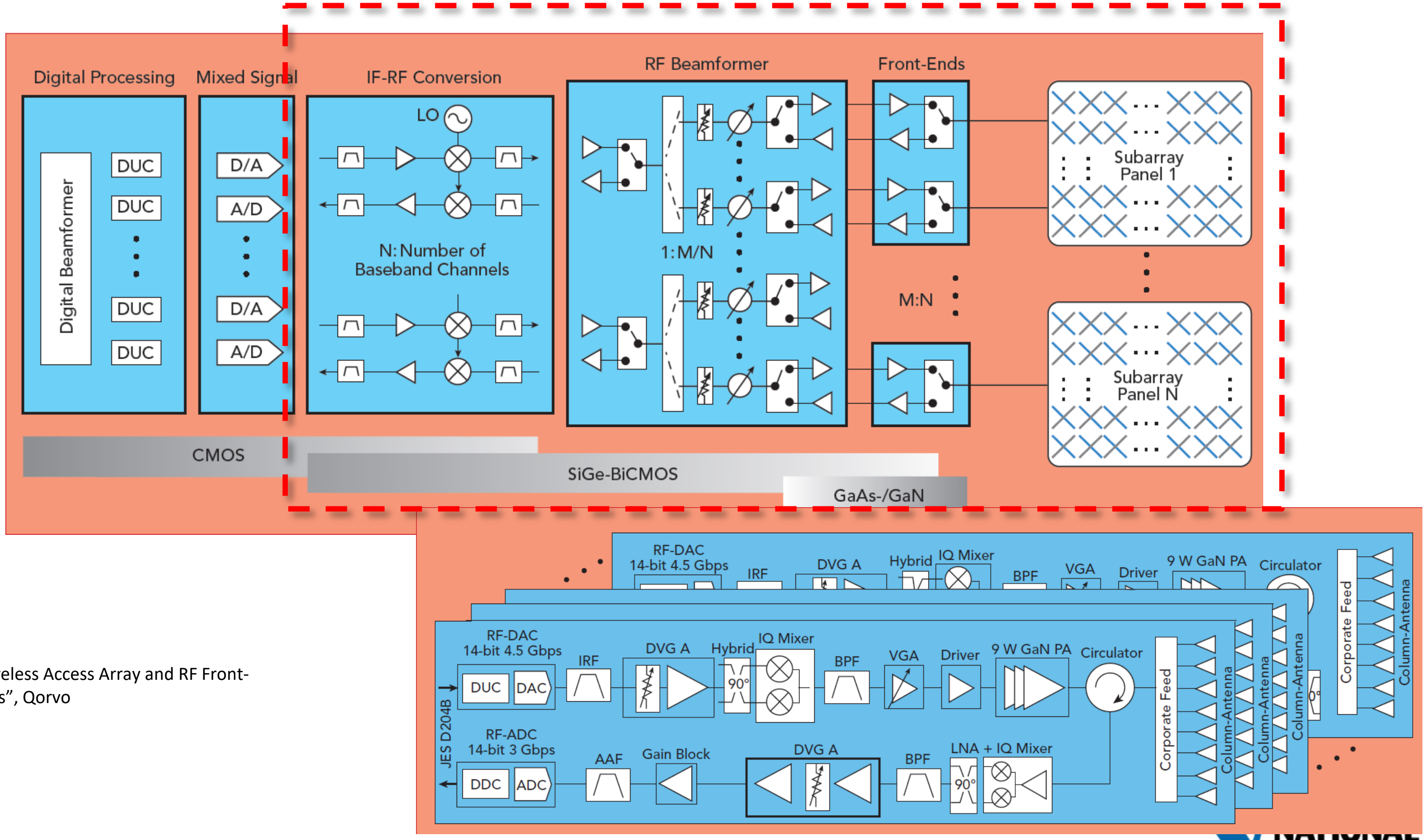
Example Calculation !!

"5G Cellular User Equipment: From Theory to Practical Hardware Design", Yiming Huo, et al.

BFM Scenario Calculation



mmWave Beamforming Topologies

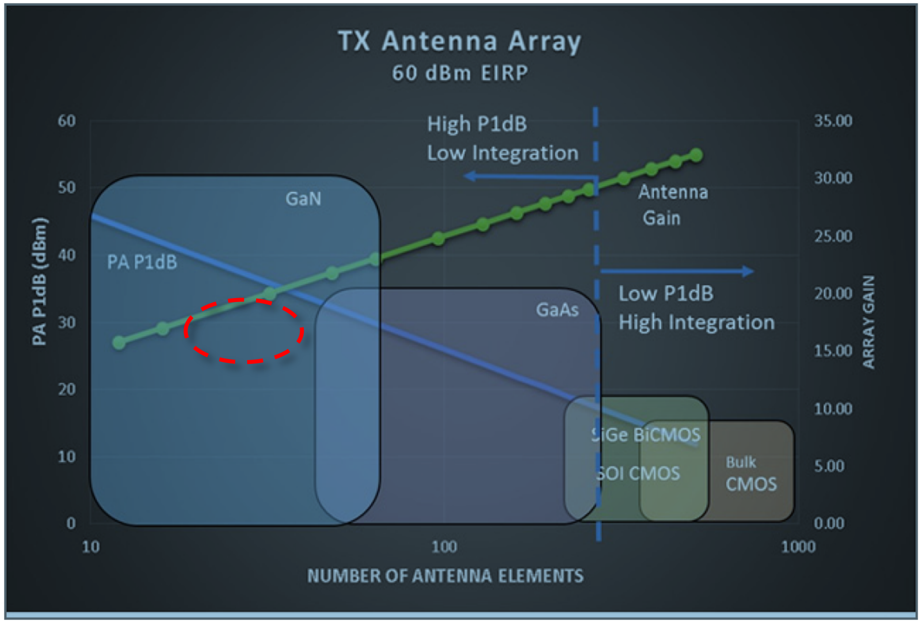


“5G Fixed Wireless Access Array and RF Front-End Trade-Offs”, Qorvo

Path loss and Link Budget Calculation

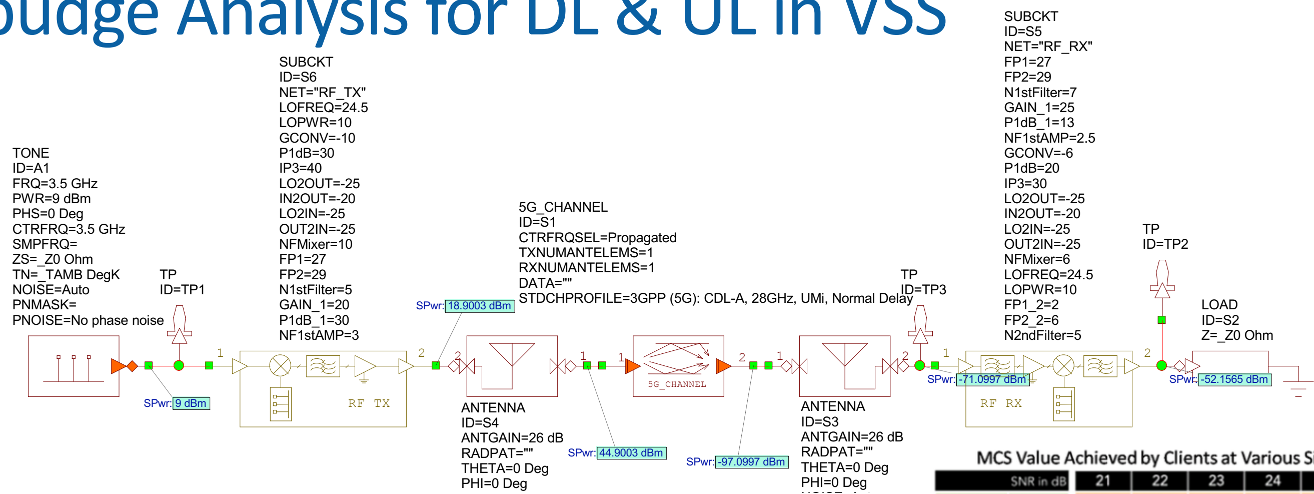
- ADI 200m NLOS Link budget example in suburban FWA

TABLE 1		
Link Budget 200m link @ 28GHz 800 MHz Bandwidth	Downlink (Basestation)	Uplink (CPE)
Antenna Element Count	256	64
Total Conducted PA power	+33dBm	+19 dBm
Antenna Gain	27 dB	21
TX EIRP	60 dBm	40dBm
Path Loss	135dB	135 dB
Received Power	-75dBm	-95 dBm
Thermal noise floor	-85 dBm	-85dBm
RX Noise Figure	5dB	5dB
SNR per RX element	5dB	-15dB
RX Antenna Gain	21dB	27dB
RX SNR after beamforming	+26dB	+12dB



"Bits to Beams – RF Technology Evolution for 5G mmwave Radios", ADI @ Microwave Journal Nov. 2018

Link-budge Analysis for DL & UL in VSS

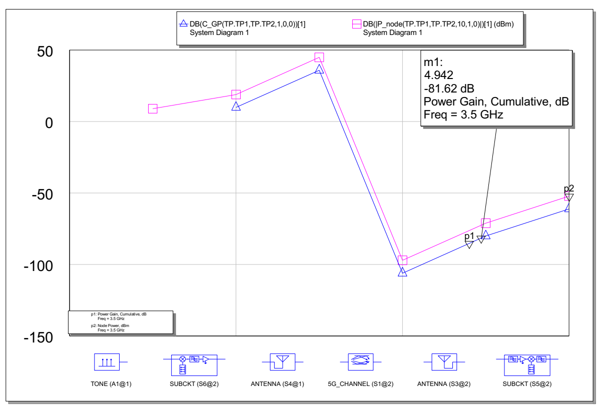


$$PRx=PTx+GTx+GRx-FSPL$$

$$Pnoise=-174+10logBW+NF$$

$$SNR=PRx-Pnoise$$

$$\mathrm{EIRP}=PTx+GTx$$



MCS Value Achieved by Clients at Various Signal to Noise Ratio Levels (SNR)

	SNR in dB	21	22	23	24	25	26	27	28	29	30
802.11b	20MHz	MCS 3	MCS 3	MCS 3	MCS 3	MCS 3	MCS 3	MCS 3	MCS 3	MCS 3	MCS 3
802.11a/g	20MHz	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7
802.11n	20MHz	MCS 6	MCS 6	MCS 6	MCS 6	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7
802.11n	40MHz	MCS 5	MCS 5	MCS 6	MCS 6	MCS 6	MCS 6	MCS 6	MCS 7	MCS 7	MCS 7
802.11ac	20MHz	MCS 6	MCS 6	MCS 6	MCS 6	MCS 7	MCS 7	MCS 7	MCS 7	MCS 8	MCS 8
802.11ac	40MHz	MCS 5	MCS 5	MCS 6	MCS 6	MCS 6	MCS 6	MCS 6	MCS 7	MCS 7	MCS 7
802.11ac	80MHz	MCS 4	MCS 4	MCS 4	MCS 5	MCS 5	MCS 6	MCS 6	MCS 6	MCS 6	MCS 6
802.11ac	160MHz	MCS 3	MCS 3	MCS 3	MCS 4	MCS 4	MCS 4	MCS 5	MCS 5	MCS 6	MCS 6

Theoretical throughput for single Spatial Stream (in Mbit/s)[a]

MCS index[b]	Modulation type	Coding rate	20 MHz channels		40 MHz channels		80 MHz channels		160 MHz channels	
			800 ns GI[c]	400 ns GI	800 ns GI	400 ns GI	800 ns GI	400 ns GI	800 ns GI	400 ns GI
0	BPSK	1/2	6.5	7.2	13.5	15	29.3	32.5	58.5	65
1	QPSK	1/2	13	14.4	27	30	58.5	65	117	130
2	QPSK	3/4	19.5	21.7	40.5	45	87.8	97.5	175.5	195
3	16-QAM	1/2	26	28.9	54	60	117	130	234	260
4	16-QAM	3/4	39	43.3	81	90	175.5	195	351	390
5	64-QAM	2/3	52	57.8	108	120	234	260	468	520
6	64-QAM	3/4	58.5	65	121.5	135	263.3	292.5	526.5	585
7	64-QAM	5/6	65	72.2	135	150	292.5	325	585	650
8	256-QAM	3/4	78	86.7	162	180	351	390	702	780
9	256-QAM	5/6	N/A	N/A	180	200	390	433.3	780	866.7

Use HT40 MCS7 on 802.11ac that SNR must have greater than 28dB

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Design Equations/Goals

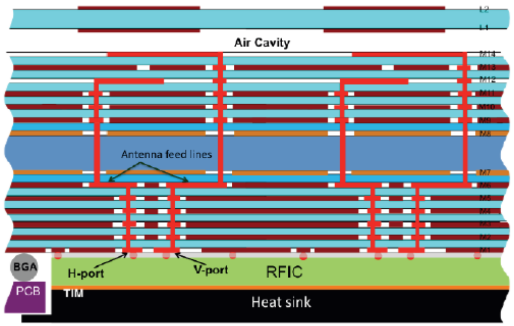
- NLOS/LOS Path Loss:125/95 dB
- Element Antenna Gain: 6
- Array Gain: 9+6 dB (X/Y)
- Beam Width: 10º/>30º (Scanned X/ Fixed Y)
- TX PA Output Power:
  - Linear: 24dBm
  - Psat: 33 dBm
- EIRP:
  - Linear: 45dBm
  - Psat: 54dBm

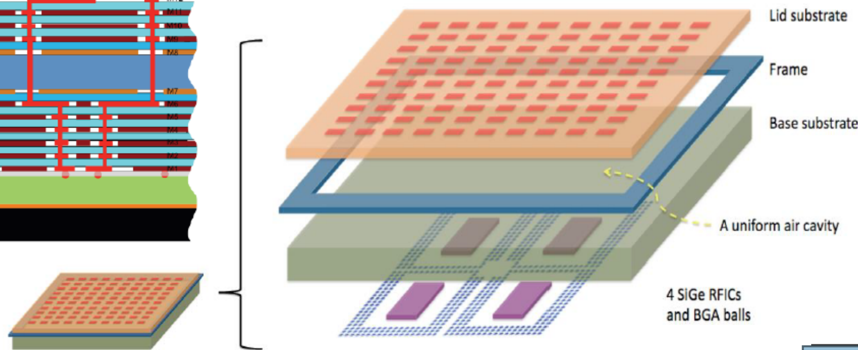
Ideal Array Factor

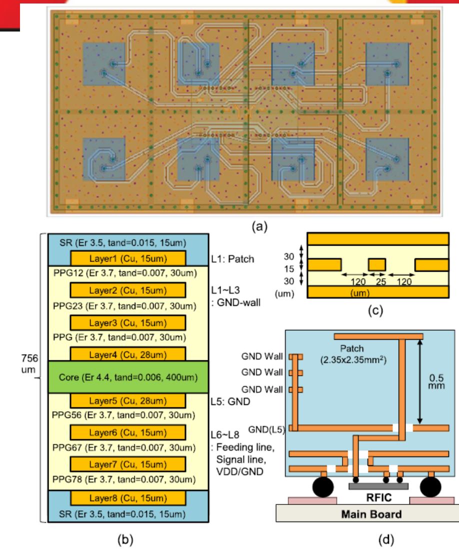
M (x-axis)	N (y-axis)	Max Gain (dB)	Beam width 2D (degree)
2	1	3	60
4	1	6	34
8	1	9	18
2	2	6	60
4	4	12	34
8	8	18	18

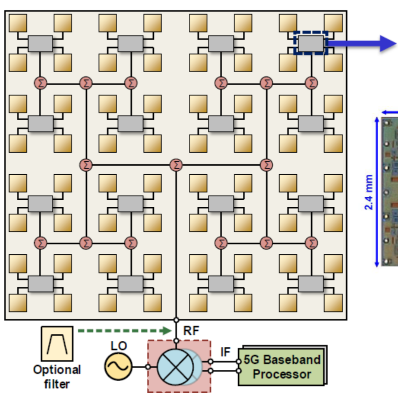
Element Patch Antenna for 28GHz

28 GHz Si-based Integrated BFM

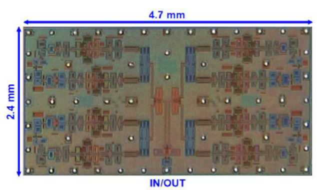




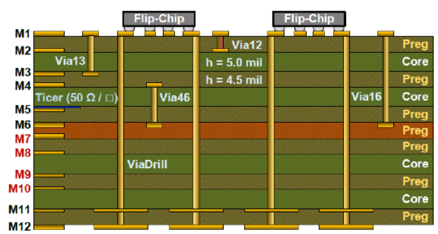




2x2 TRX Beamformer



12-layer PCB



	This work (ISSCC 2017 / IMS 2017)	Anokiwave (AWMF-0129 Datasheet)	UCSD (RFIC 2017)	LG (RFIC 2017)	UCSD (IMS 2017)
Number of Antennas	64	64	32	8	4
Simultaneous polarizations	**2**	**1**	**1**	**2**	**1**
FE Elements in Package/Board	**128**	**64**	**32**	**16**	**4**
Number of ICs	4	8	8	2	1
Input Interface	**IF 3GHz**	**Not published**	**RF 28GHz**	**Baseband**	**RF 28GHz**
EIRP per polarization	**54dBm (Psat)**	**50dBm (P1dB)**	**41dBm (P1dB) @29GHz**	**31.5dBm (Psat)**	**24.5dBm (P1dB) @29GHz**
DC power per polarization	13.2W(RX) + 20.4W(TX) @54dBm EIRP	18W (average)	4.2W (RX) + 6.4W(TX)	0.4W(RX) + 0.68W(TX) @24dBm EIRP	0.42W(RX) + 0.8W(TX)
IC Technology	GF SiGe 8HP 130nm	Not published	Jazz SBC18H3 SiGe BiCMOS	TSMC 28nm RF CMOS	Jazz SBC18H3 SiGe BiCMOS

“A Scalable 64-Element 28 GHz Phased-Array Transceiver with 50 dBmEIRP and 8-12 Gbps5G Link at 300 Meters Without Any Calibration,” IMS2018
“A 28-GHz CMOS Direct Conversion Transceiver With Packaged 2 × 4 Antenna Array for 5G Cellular System” JSSC May 2018
“Phased Array Innovations for 5G mmWvae Beamforming,” IEEE 5G Summit, IBM 2015

Nokia 28GHz Backhaul

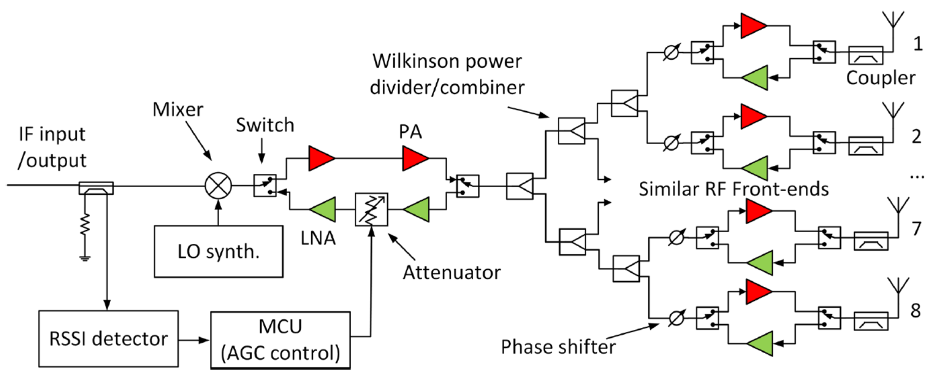
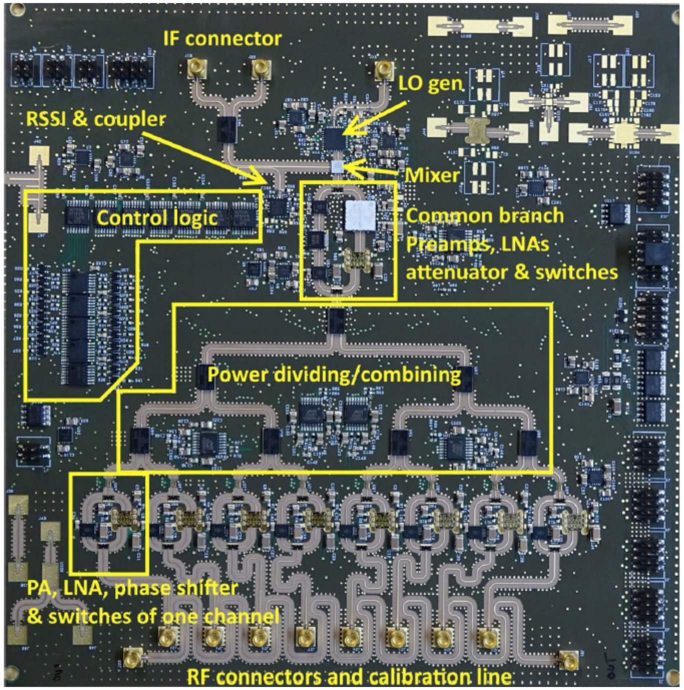
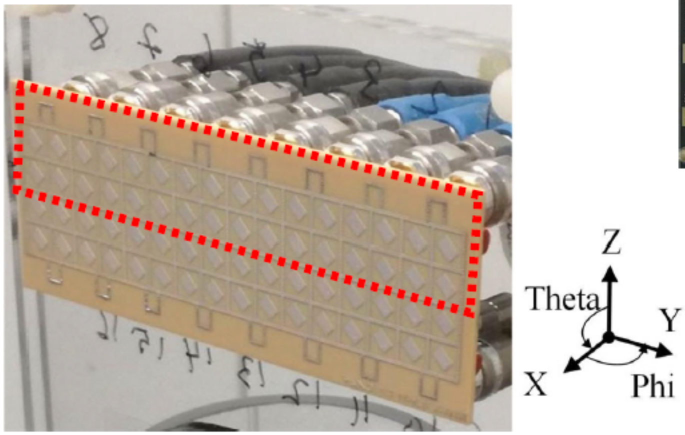


Fig. 1 A partial block diagram of the transceiver (branches 3, 4, 5, and 6 are not shown to improve clarity)

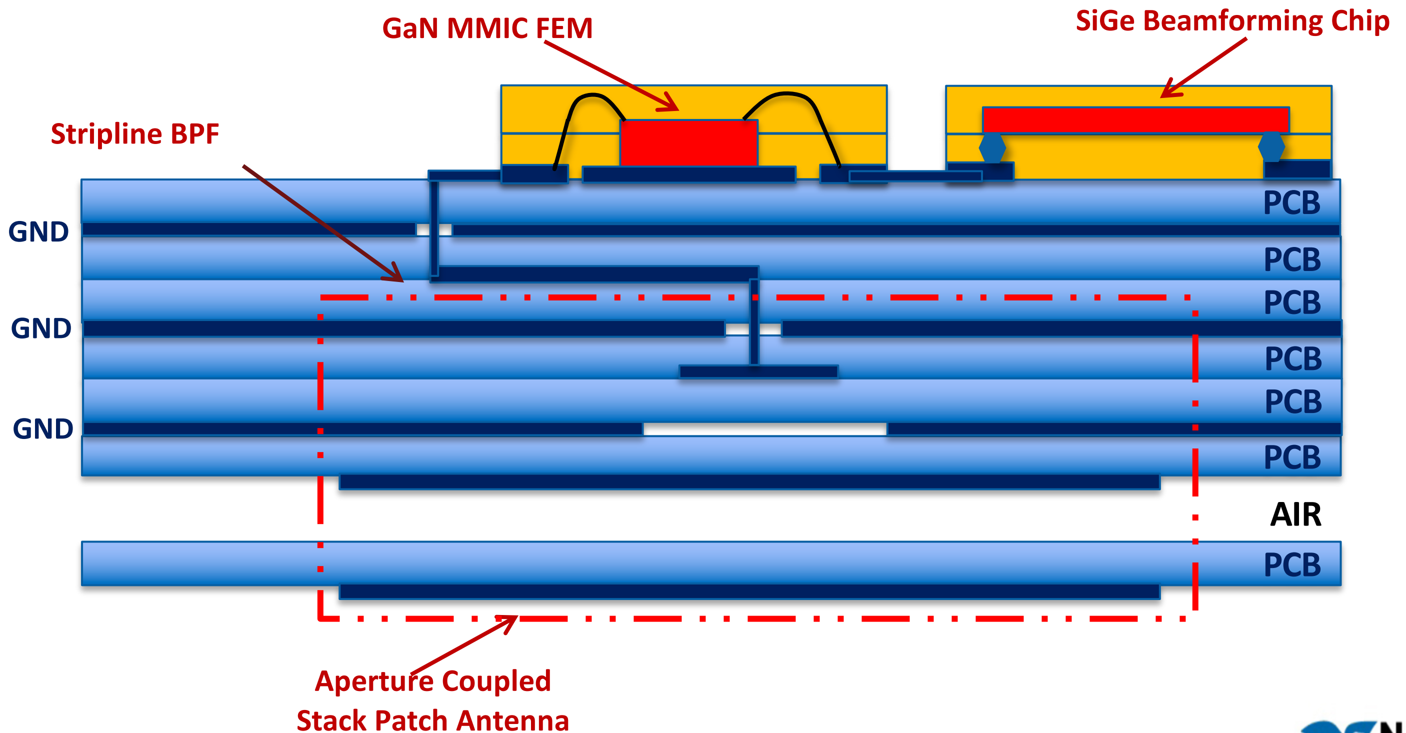




“Design and measurement of a 5G mmW mobile backhaul transceiver at 28 GHz,” *EURASIP Journal onWireless Communications and Networking* (2018)

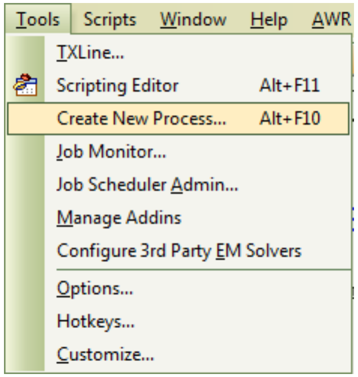
Create New Process for BFM

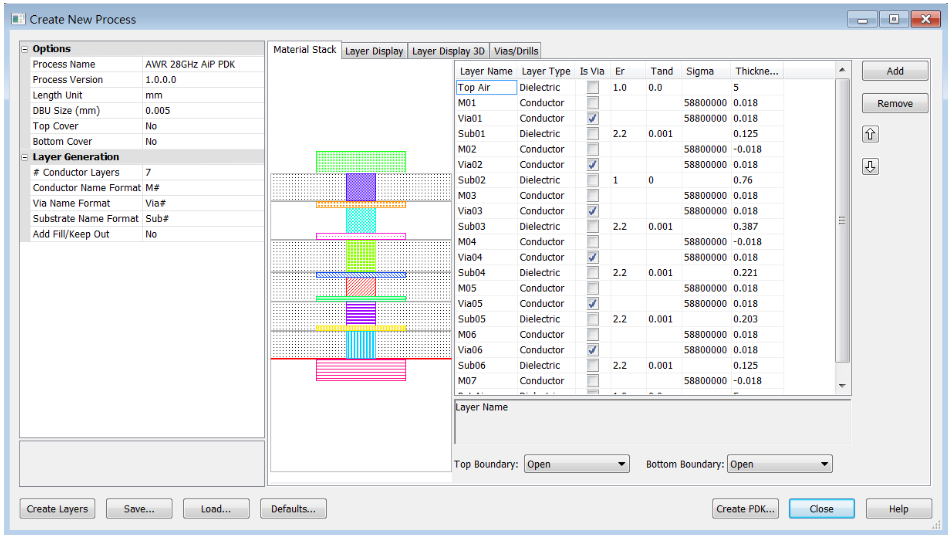
- Simplified Beam Forming Module's structure:



Create Your Process – Multilayer PCB

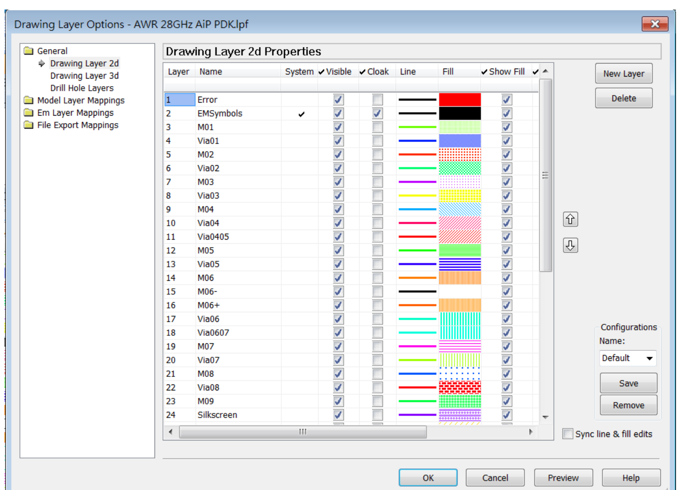
- You may use the “Create New Process” tool in order to define the process of your project
- In this example – a multilayer PCB with air frame

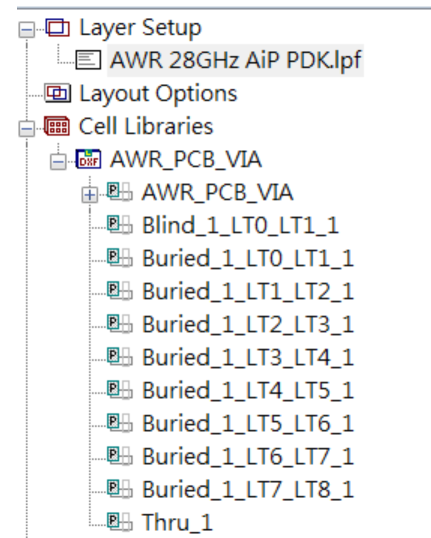




Create Your Process

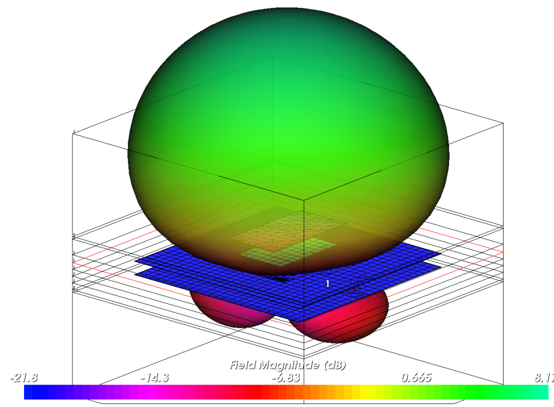
- The new process generates the following:
  - Global definitions: multiple MSUB and STACKUP models
    - You may add or modify them
  - A new layout process file (LPF)
  - Including an automatic mapping of schematic's layout and EM layout
  - VIA models

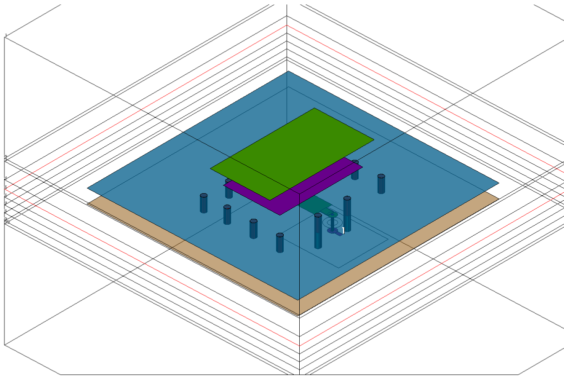


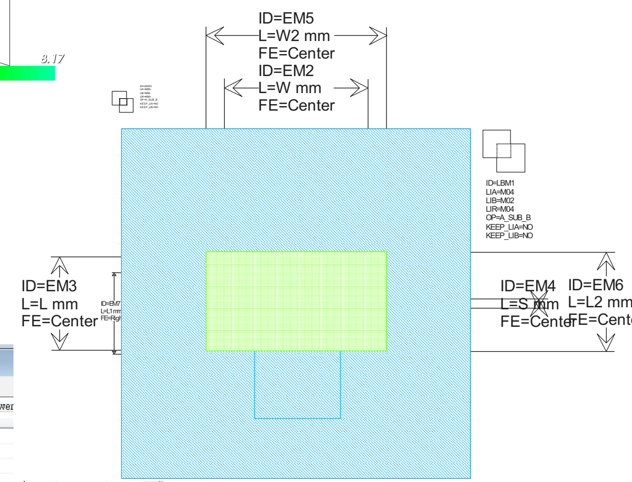


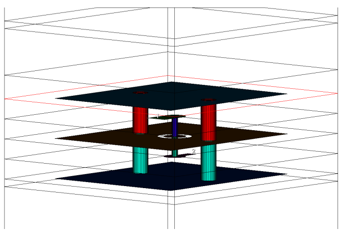
Optimization of Multilayer Patch Antenna

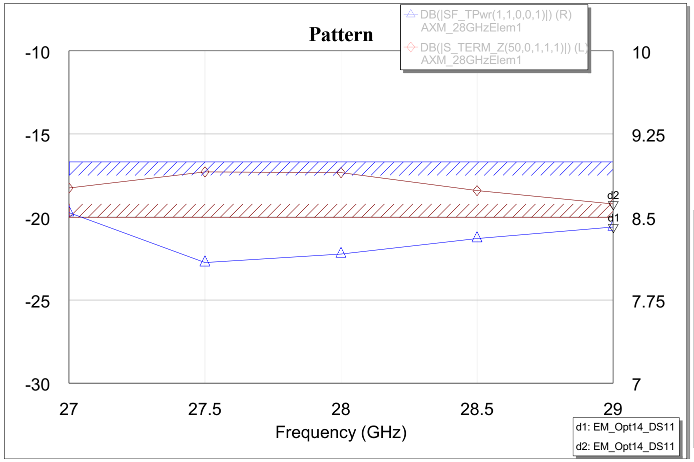
- Shape Modifier in Layout
- Parameters in Stackup
- Optimization Goals of Antenna Gain and RL









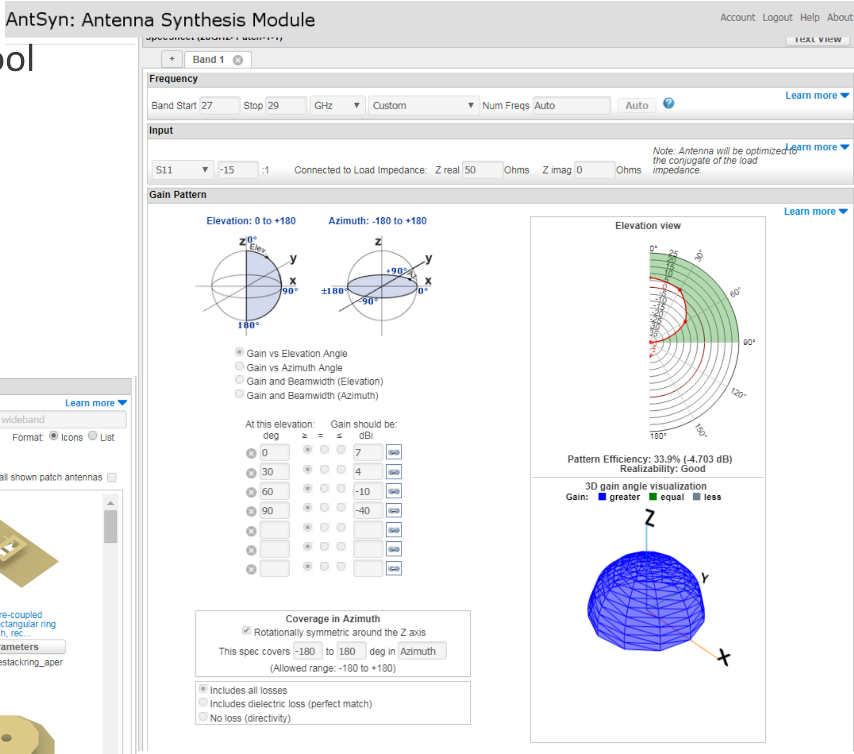


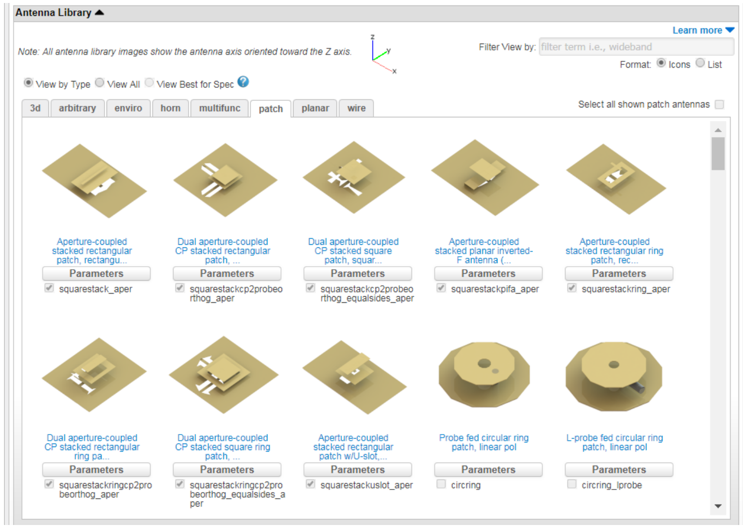
Variables (Showing 55 of 55)

Document	Element	ID	Parameter	Value	Tune	Optimize	Constrain	Lower	
AXM_28GHzElem1	EQN		L1	2.32979751462902	☐	☑	☑	1.5	
AXM_28GHzElem1	EQN		W2	5.17935968748684	☐	☑	☑	4.8	
AXM_28GHzElem1	EQN		W	4.12090077706684	☐	☑	☑	4	
AXM_28GHzElem1	EQN		W_SL	0.847410672372997	☐	☑	☑	0.4	1
AXM_28GHzElem1	EQN		S	0.259687061823448	☐	☑	☑	0.1	0.3
AXM_28GHzElem1	EQN		L	2.67717744263465	☐	☑	☑	2.5	2.9
AXM_28GHzElem1	EQN		L2	2.84182301252336	☐	☑	☑	2.6	3
AXM_28GHzElem1	EQN		H1	0.387	☐	☑	☑	0.25	0.635
AXM_28GHzElem1	EQN		H2	0.76	☐	☑	☑	0.7	1
AWR 28GHz AiP PDK	EQN		_TEMP	27	☐	☐	☐		

Antenna Design With AntSyn

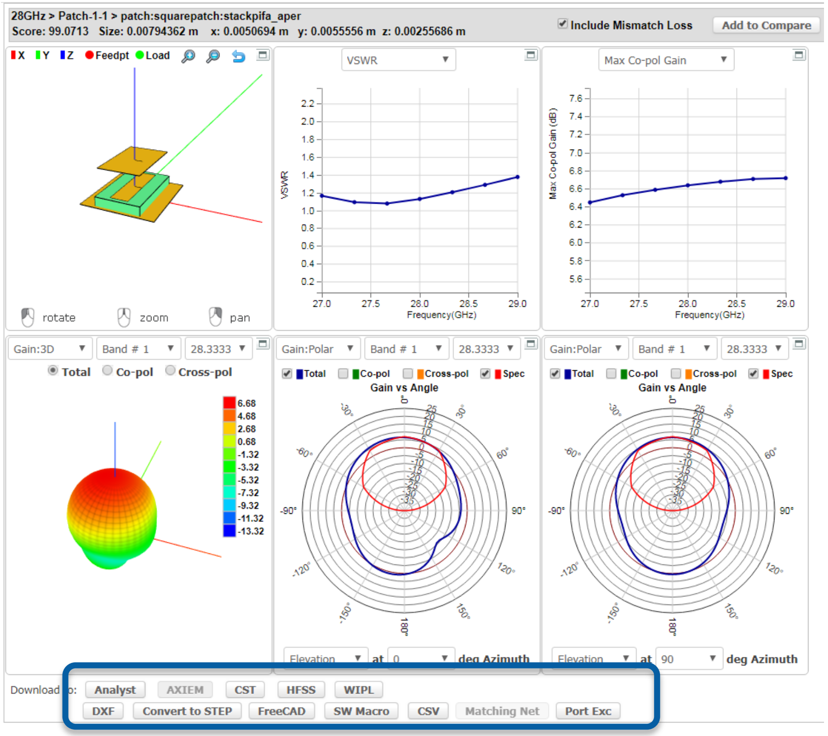
- AntSyn™ is an EM-based antenna design and synthesis tool
- Set the antenna goals
- Choose any antenna from a large and flexible data base
- AntSyn will optimize the antenna for you

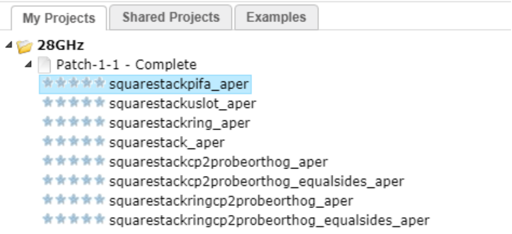




Antenna Design With AntSyn

- In this example, AntSyn is used for a multilayer patch antenna optimized to 28 GHz
- The design are reached
- The model can be automatically exported to several EM tools, including AXIEM and Analyst™





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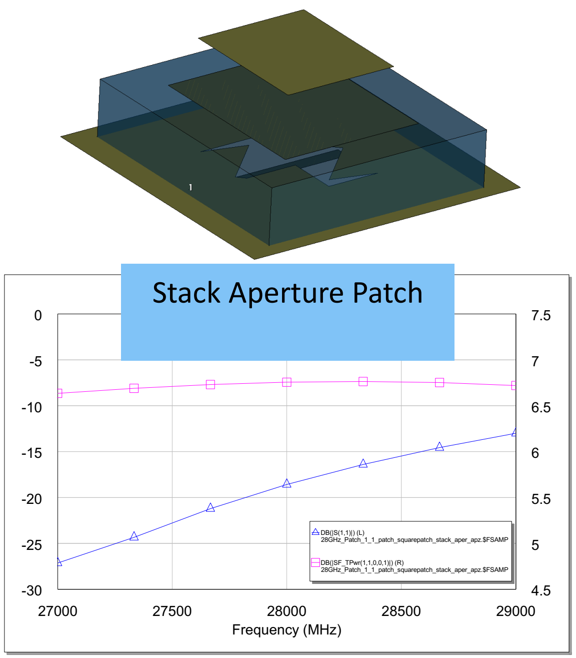
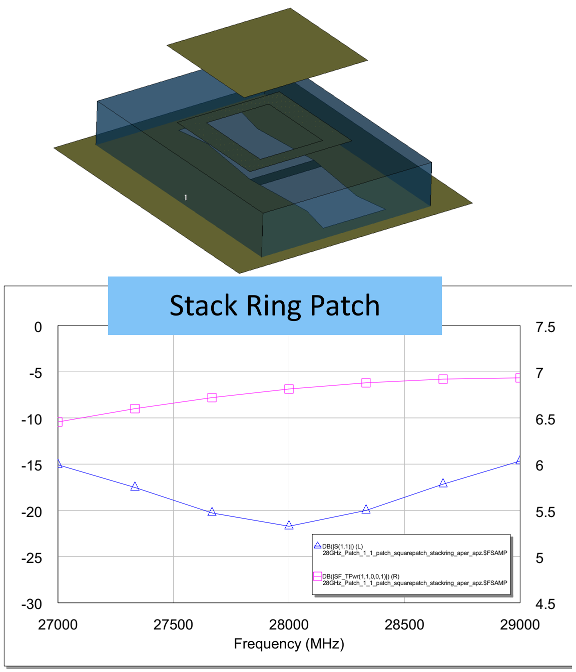
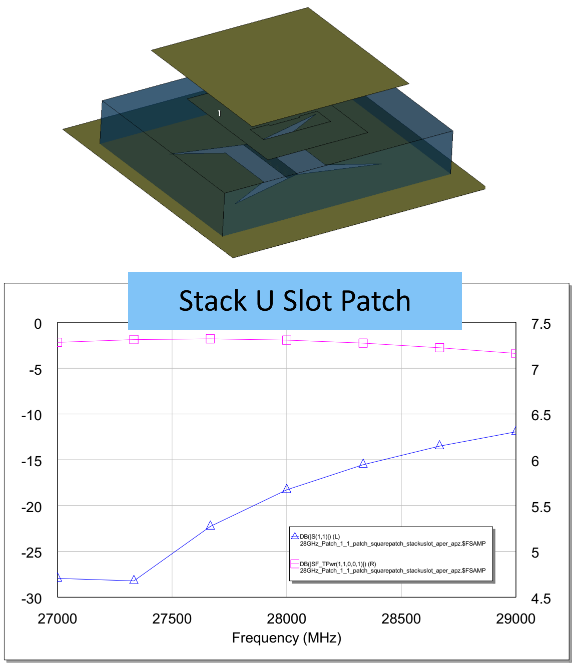
AntSyn Stack Patch Verification in Analyst

- 4-12mins solving time with Analyst 3D EM







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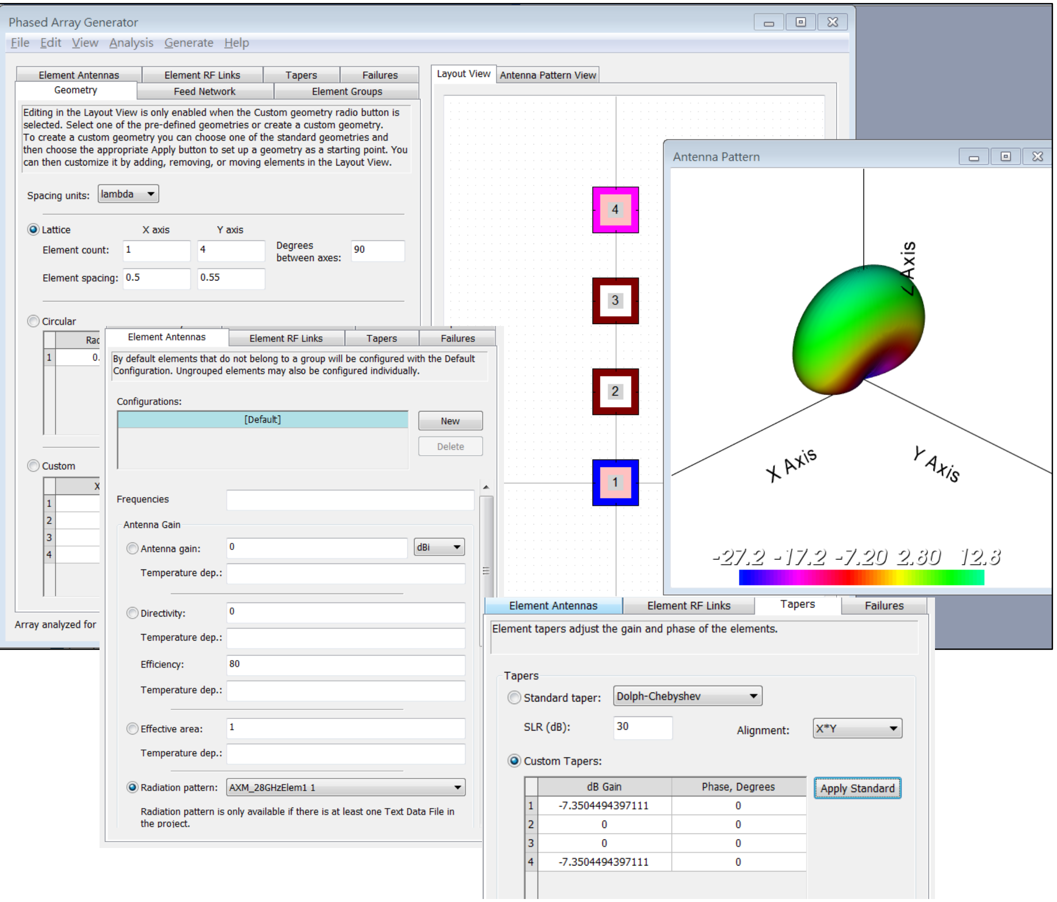
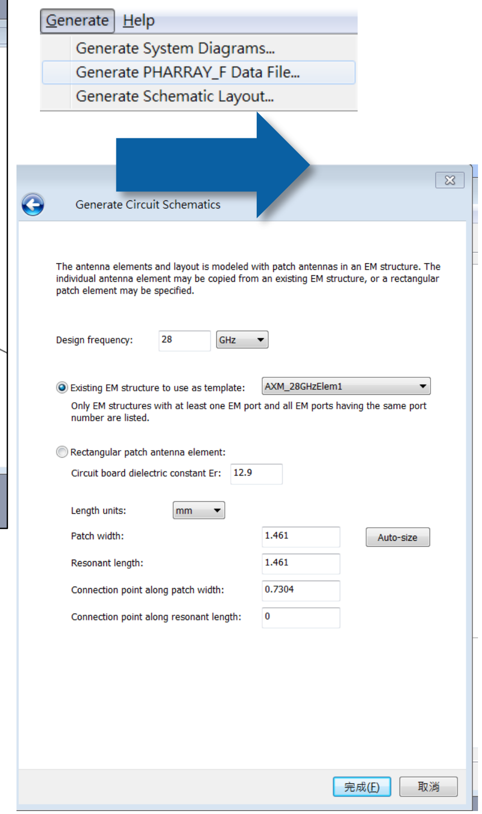
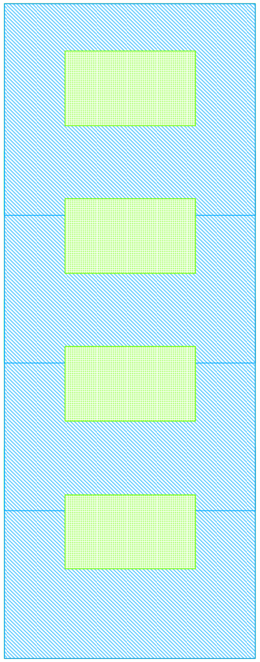
Feed Network Co-simulation of Antenna Array

1x4 Fixed Antenna Array at Y-axis







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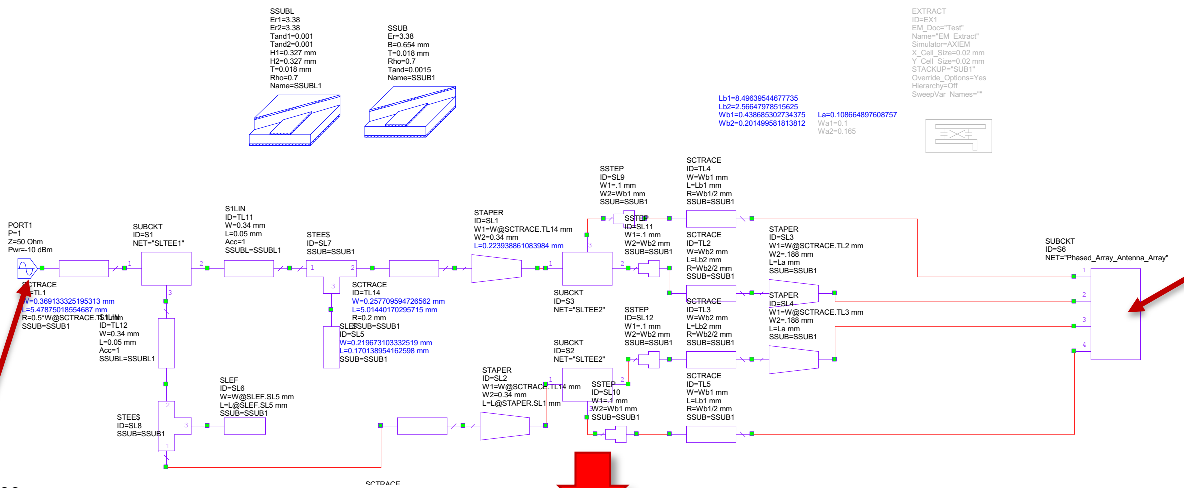
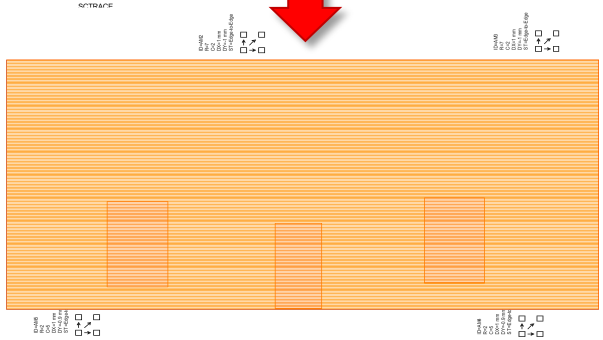
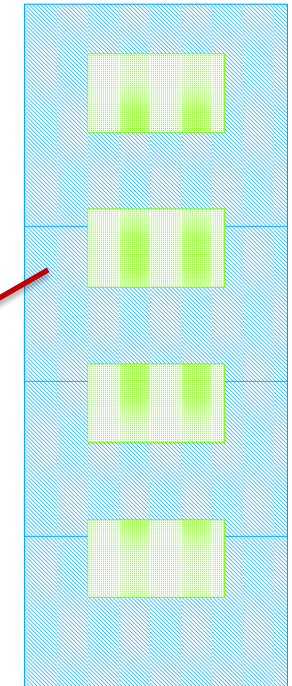
HB-EM Co-simulation for Antenna Pattern & RL

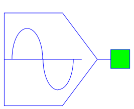




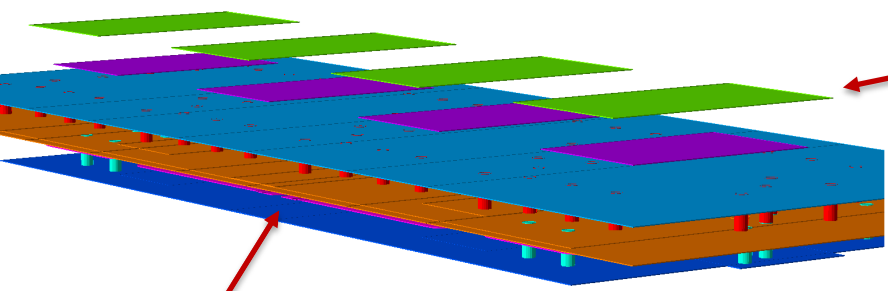


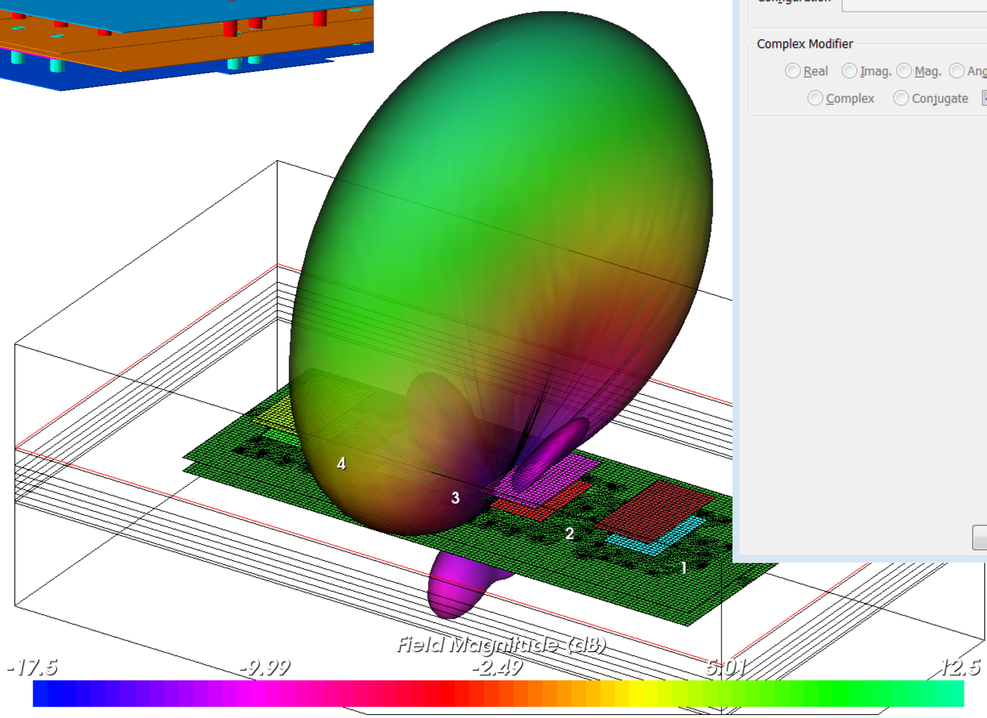
~1 hr EM Solving

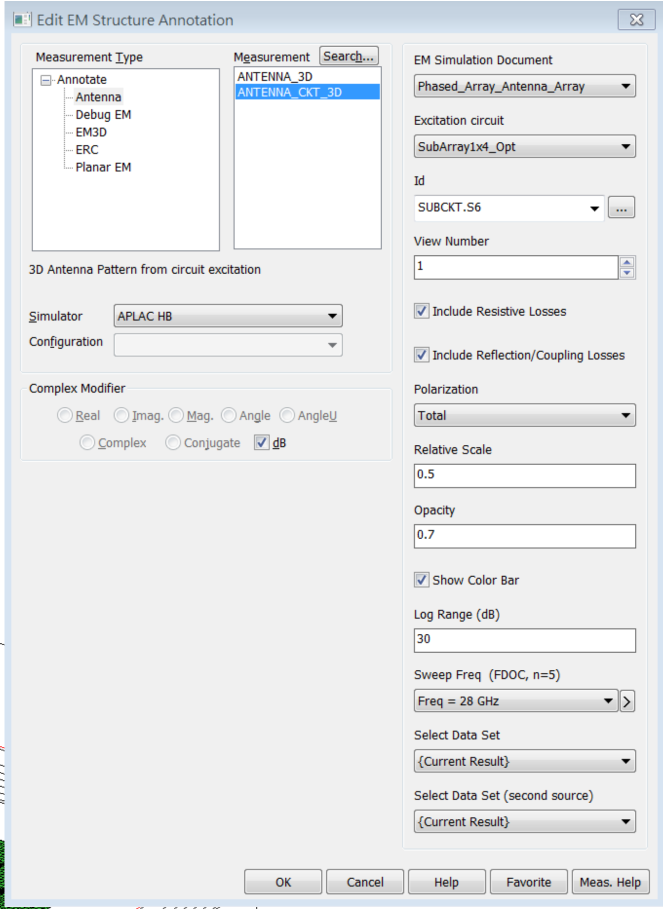
PORT1
P=1
Z=50 Ohm
Pwr=-10 dBm



Whole 3D Layout and Pattern

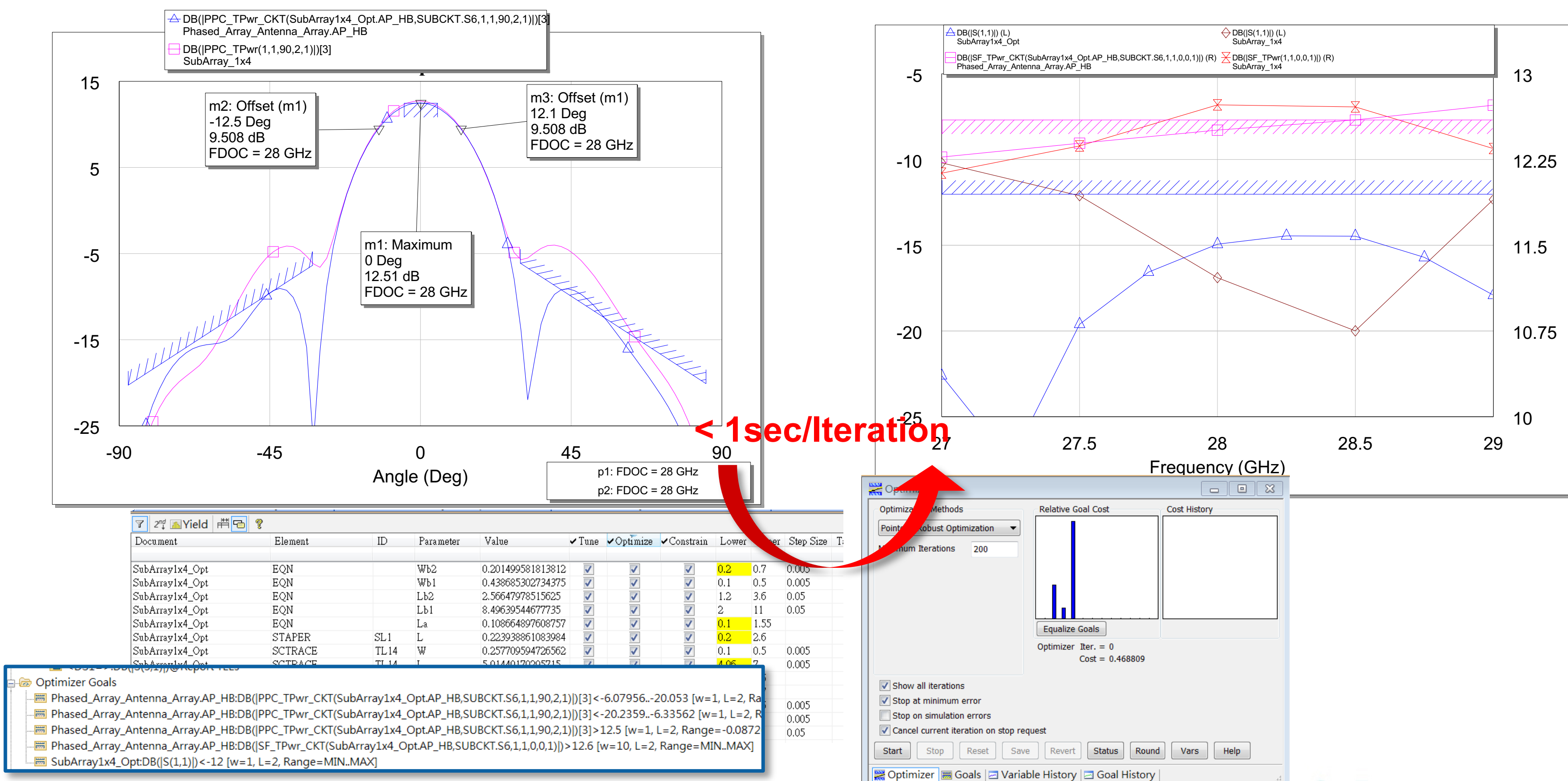






NATIONAL INSTRUMENTS

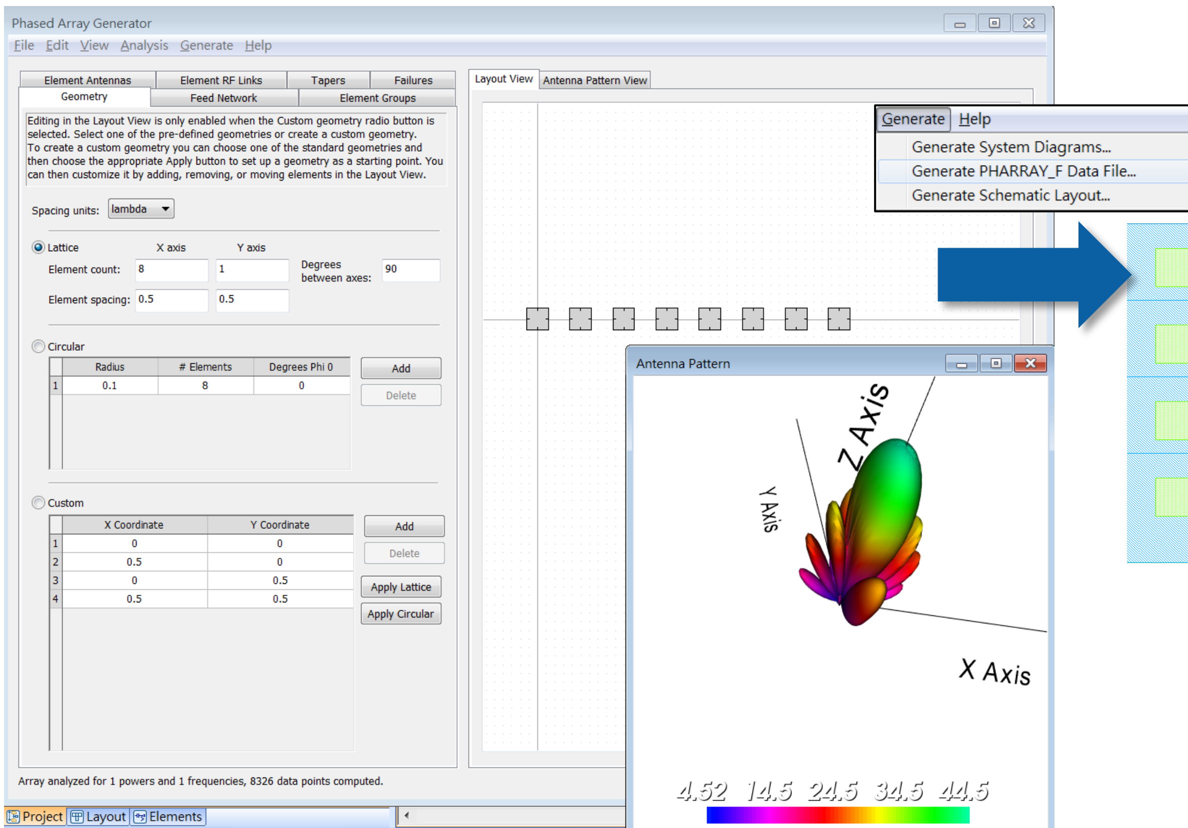
Optimization for Sidelobe Rejection, Gain, RLs

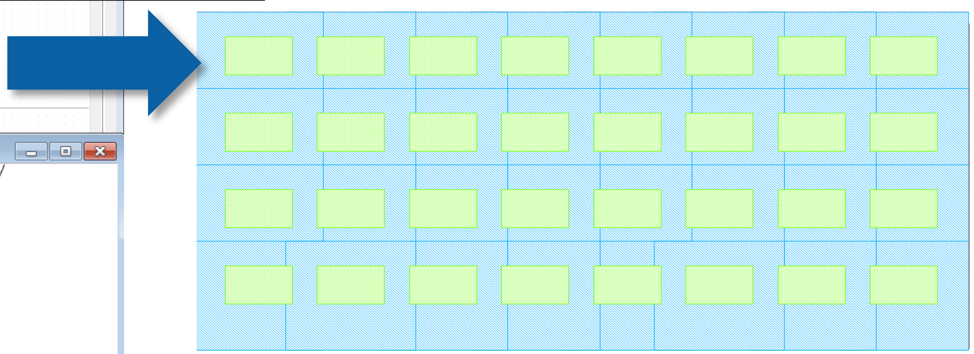


Active Electronically Scanned Array (AESA)

For 5G Pole Size Small Cell BS

1x8 Phased Array at X-axis with FEM PA

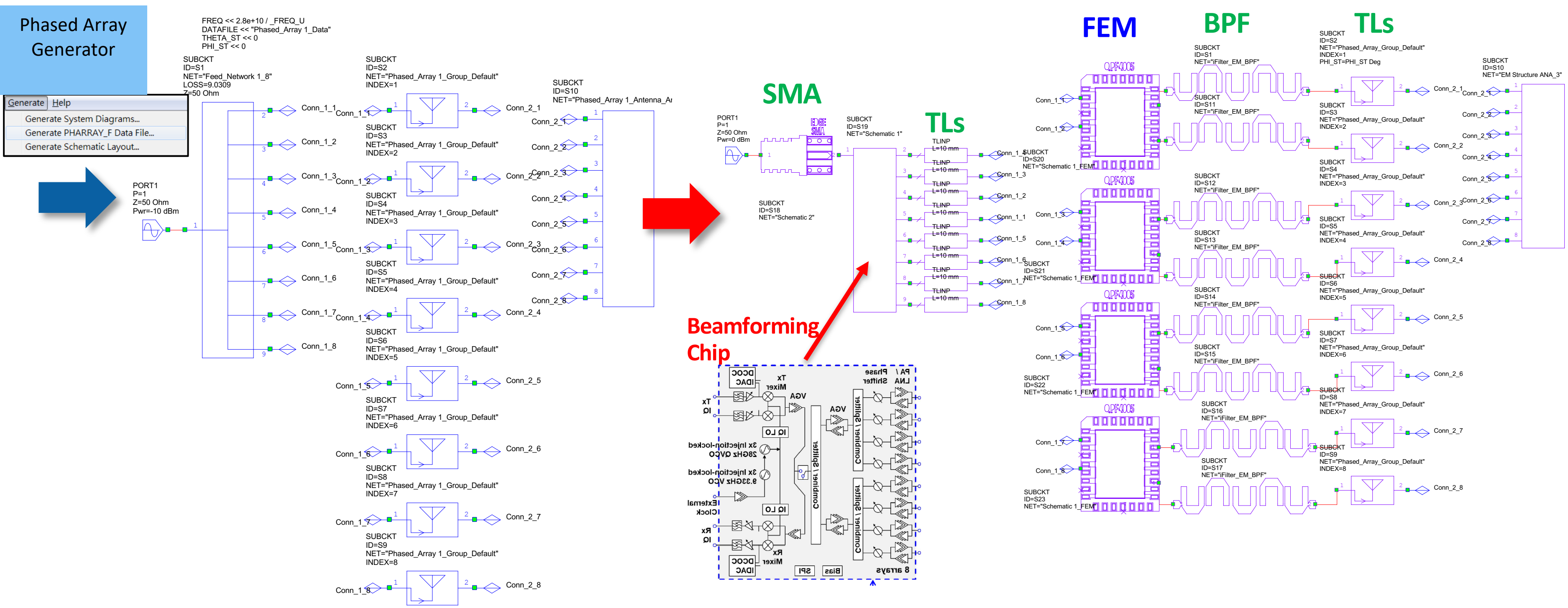




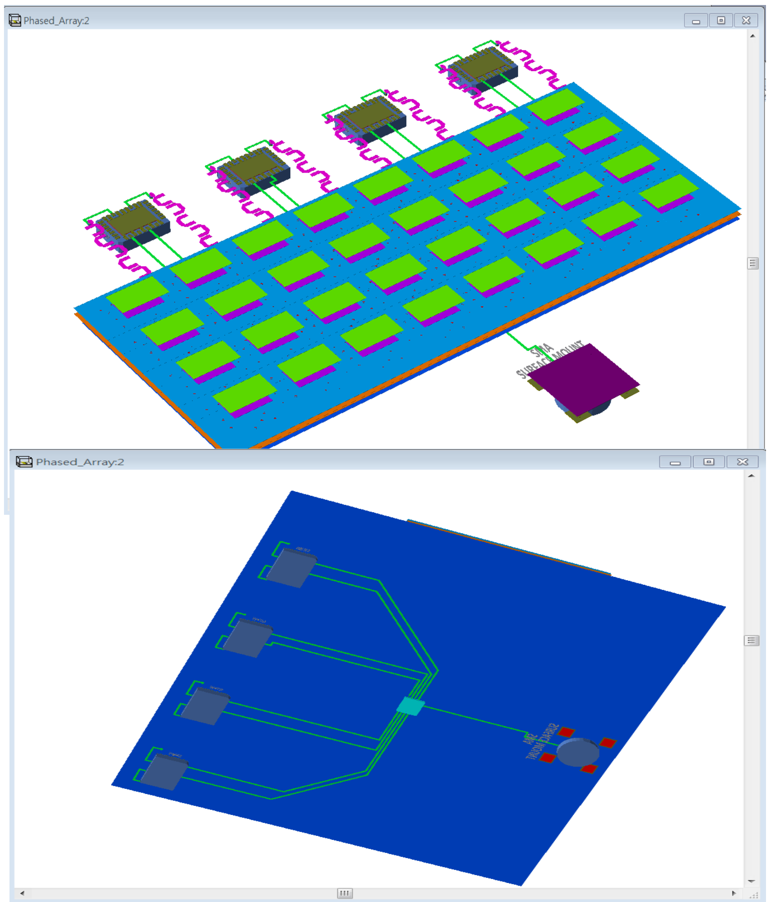
60 x 26 mm^2

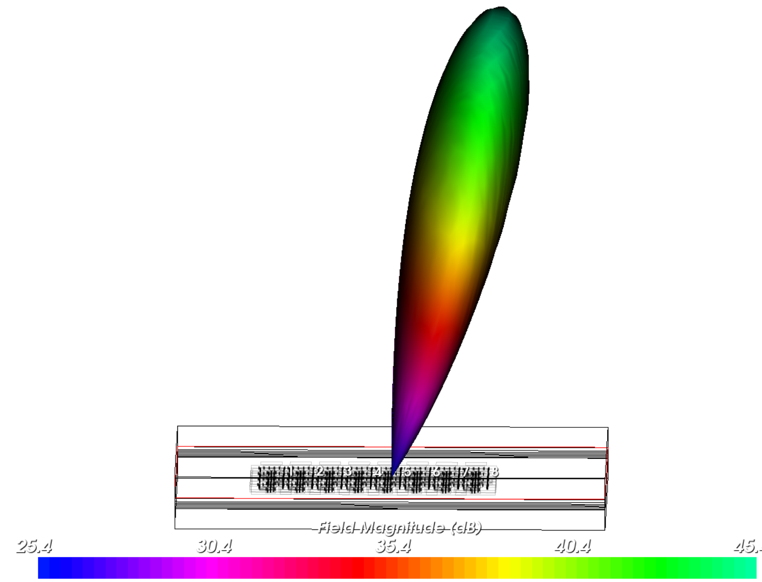
NATIONAL INSTRUMENTS

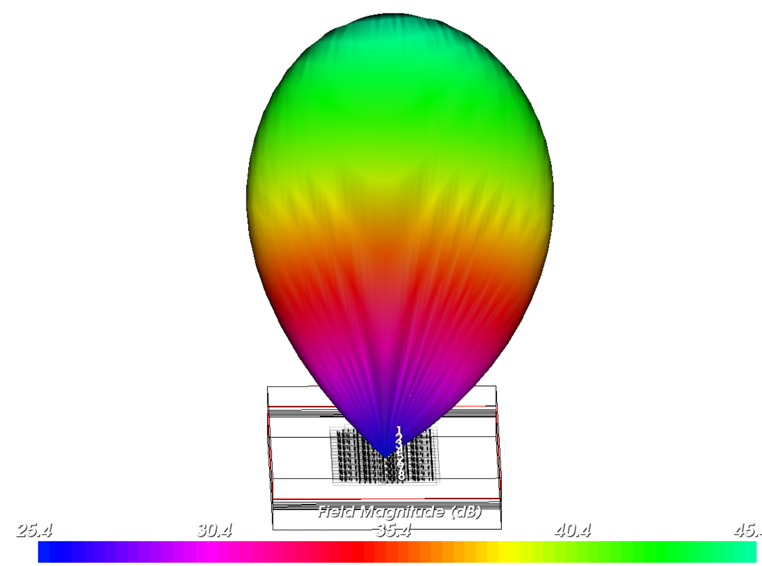
Realize Feed Structure of Active Electronically Scanned Array (AESA)



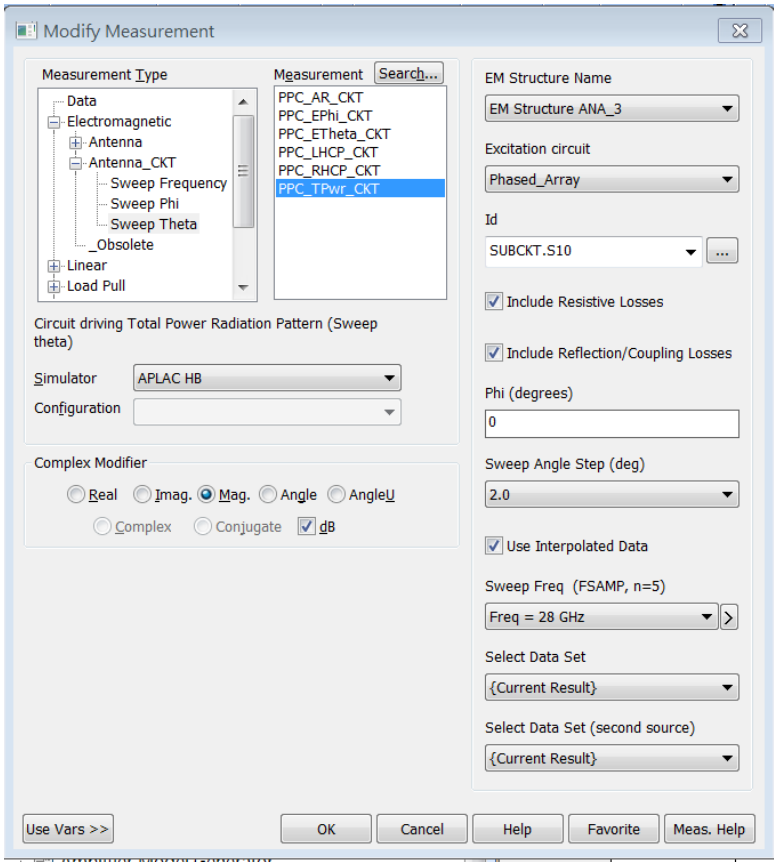
Circuit Driven AESA Radiatior

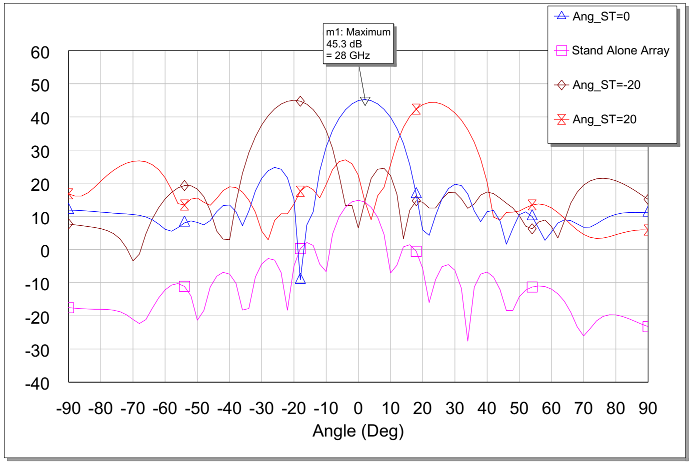


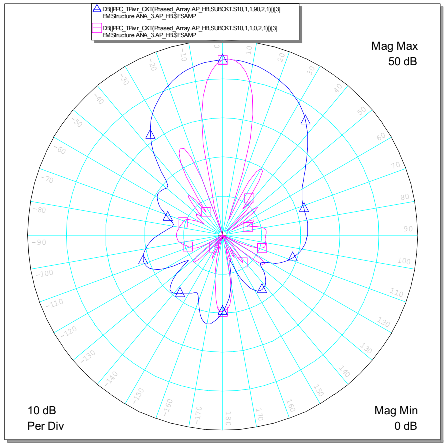




Stand Alone Array vs. AESA Co-Simulation

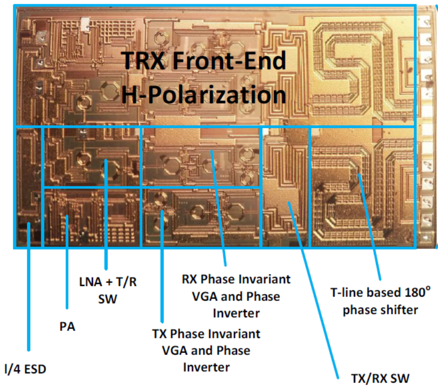




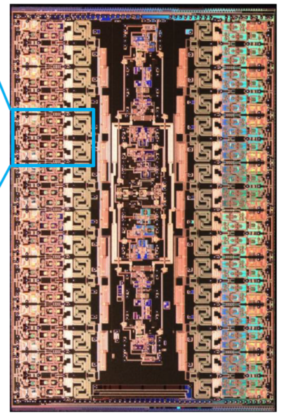


IBM/Ericsson

28-GHz Dual-polarized TRX Front-End Breakout

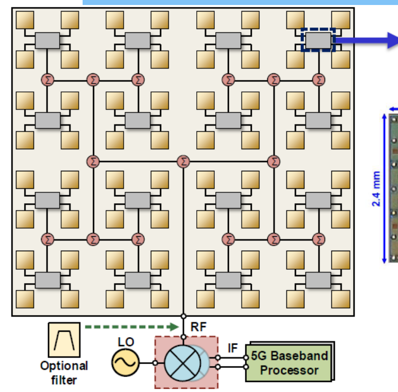


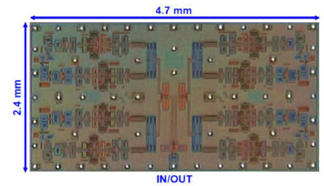
32 TX, 32 RX, 28-GHz Phased Array IC



15.8 x 10.5 mm^2

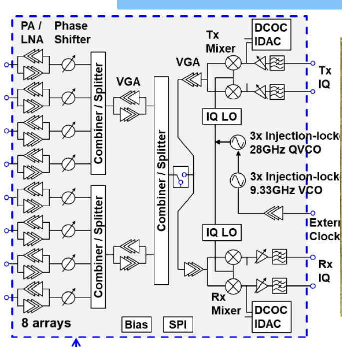
UCSD



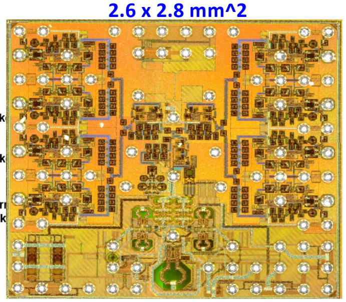


Parameter	This work	Qualcomm '18 [1]	LG '18 [2]	IBM '17 [3]	UCSD '18 [4]
Process	**0.18 μm SiGe BiCMOS**	28 nm LP-RF CMOS	28 nm LP CMOS	0.13 μm SiGe BiCMOS	0.18 μm SiGe BiCMOS
Elements per chip	**4 TRX**	2x8 + 8 TRX	8 TRX	2x16 TRX	4 TRX
Elements in array	**64 TRX**	2x4 + 4 TRX	2x8 TRX	2x64 TRX	32 TRX
Chip area (mm^2)	**11.3**	27.8	7.3	165.9	11.7
IC integration level	**RF front-end**	RF front-end + PLL + RF/IF conversion	RF front-end + VCO + RF/IQ conversion	RF front-end + RF/IF conversion	RF front-end
Polarization	**Single**	Dual	Dual	Dual	Single
RF gain cont. RX (dB)	**26**	9	22	8	14
RF gain cont. TX (dB)	**20**	8	42	8	14
Phase step (°)	**5.6**	45	45	4.9	5.6
E- / H-plane scan (°)	**±25 / ±50**	±45 / ±45	- / ±20	±50 / ±50	±25 / ±50
Sidelobe level (dB)	**<−10**	<−7	<−9	<−12	<−12
TX OP$_{1dB}$ / el. (dBm)	**12**	>12	9.5	13.5	10.5
TX OP$_{sat}$ / el. (dBm)	**13**	>14	10.5	16	12.5
RX IP$_{1dB}$ (dBm)	**−21.0**	-	-	−22.5	−22.0
RX NF / chip (dB)	**4.8**	4.4-4.7	6.7	6.0	4.6
TX P$_{DC}$ / el. (mW)	**220 @ P$_{1dB}$**	122 @ P$_{1dB}$	85 @ 24 dBm EIRP	319 @ P$_{sat}$	200 @ P$_{1dB}$
RX P$_{DC}$ / el. (mW)	**150**	42	50	206	130
EIRP at P$_{sat}$ (dBm)	**52**	34-35 / pol.	31.5	54 / pol.	45
Calibration	**No**	No	-	Yes	No
Over-the-air data rate	**18 Gbps 16-QAM @ 5 m 9 Gbps 64-QAM @ 300 m 12 Gbps 16-QAM @ 300 m**	100 MHz OFDM 64-QAM @ 2 m	LTE 20 MHz 64-QAM @ 2.5 m	-	6.0 Gbps 16-QAM @ 5 m 1.6 Gbps 16-QAM @ 300 m

LG



2.6 x 2.8 mm^2

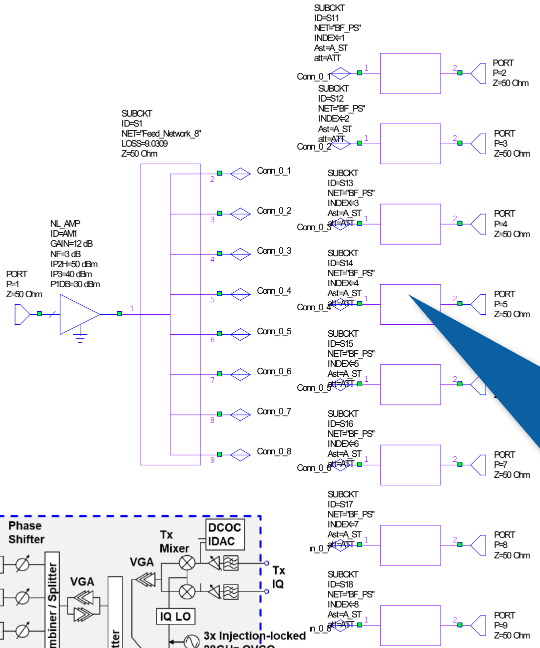


"A Scalable 64-Element 28 GHz Phased-Array Transceiver with 50 dBmEIRP and 8-12 Gbps5G Link at 300 Meters Without Any Calibration," IMS2018

"A 28-GHz CMOS Direct Conversion Transceiver With Packaged 2 × 4 Antenna Array for 5G Cellular System" JSSC May 2018

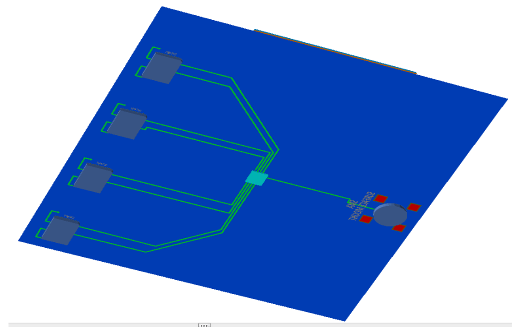
"Phased Array Innovations for 5G mmWvae Beamforming," IEEE 5G Summit, IBM 2015

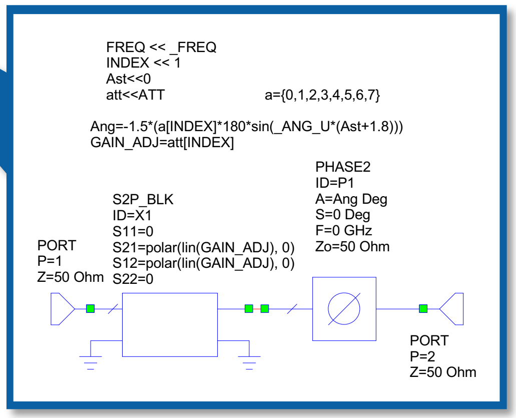
Behavior Model of Beam Forming Chip

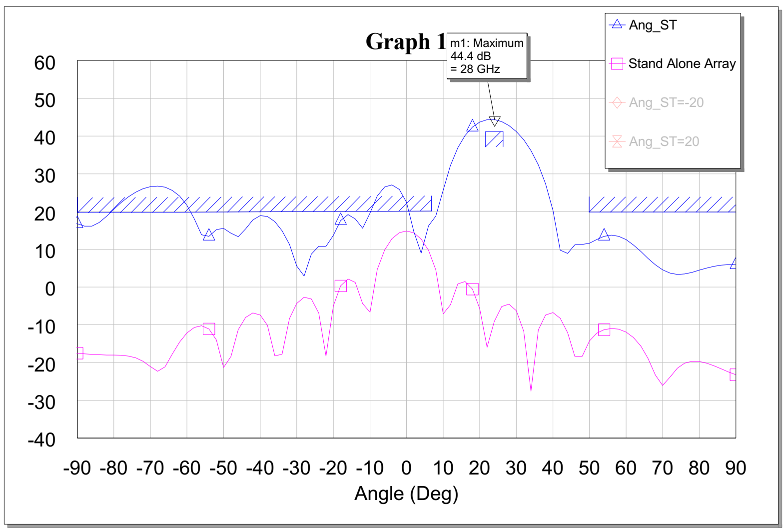


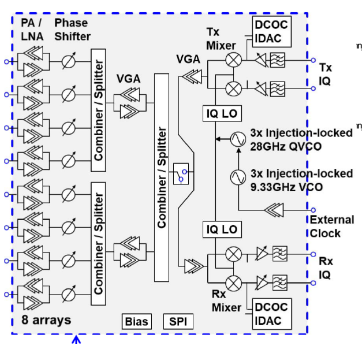
	A8=-8.6	A8=-5.041	A8=-4.2240625	A8=-5.25851654052734
	A7=-3	A7=-3.44	A7=-1.27591552734375	A7=-1.68514465332031
	A6=-1.2	A6=1.82	A6=0.865724792480469	A6=-1.36252960205078
	A5=3.1	A5=3.62	A5=2.50826245117188	A5=-1.02413464355469
	A4=3.1	A4=2.50	A4=1.90167138671875	A4=0.870636352539063
	A3=-1.2	A3=1.21	A3=0.626047973632813	A3=1.77470080566406
	A2=-3	A2=-2.78	A2=-6.82016510009766	A2=-1.6570849609375
A_ST<<10	A1=-8.6	A1=-15.44	A1=-10.7299331665039	A1=-12.3246618652344

ATT={A1,A2,A3,A4,A5,A6,A7,A8}

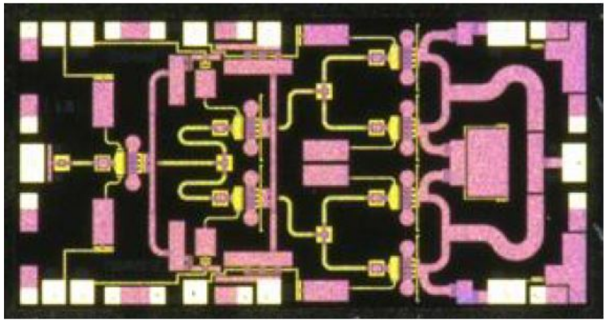


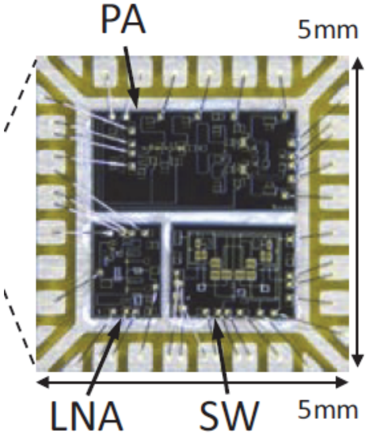


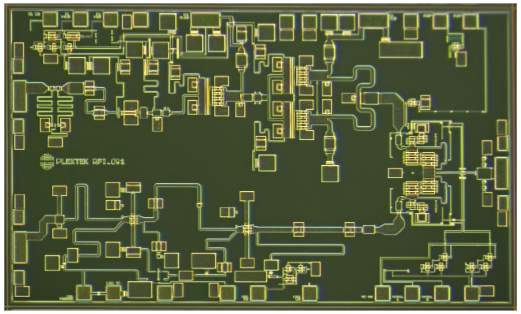




PA and FEM for 28GHz Application

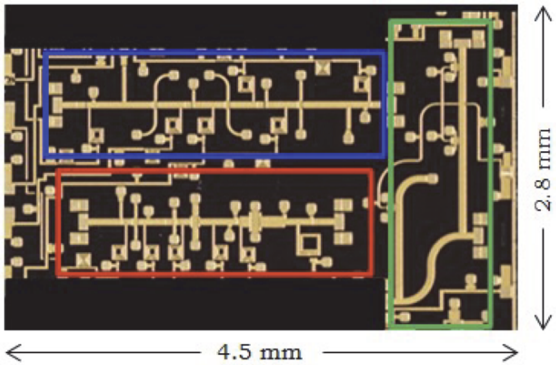






Plextek RFI 3.4x2 mm^2

Plextek white paper: Case Study – Single Chip Front End Module (FEM) for 28GHz 5G



Samsung IMS2016

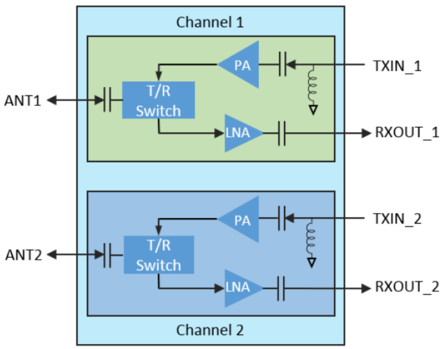
Ref #	Process Tech.	# Stages	Freq. (GHz)	Gain (dB)	Power (dBm)	PAE (%)	Die Area mm^2
[1]	GaAs	3	30	22	38.5	20	22.0
[2]	GaAs	3	30	24	36.5	22	8.6
[3]	GaAs	3	29	24	36.3	32	16.3
[4]	GaAs	3	30	21	36.0	31	14.0
[5]	GaN	2	27	13	37.0	20	14.4
[6]	GaN	2	28	13	36.0	24	--------
[7]	GaN	2	29	22	39.7	29	17.2
[8]	GaN	3	28.5	24	39.4	26	9.7
[8]	GaN	3	29	25	37.0	30	4.8
MMIC1	**GaN**	**3**	**30**	**28**	**40.4**	**30**	**11.7**
MMIC2	**GaN**	**3**	**29.5**	**28**	**37.8**	**34**	**5.6**

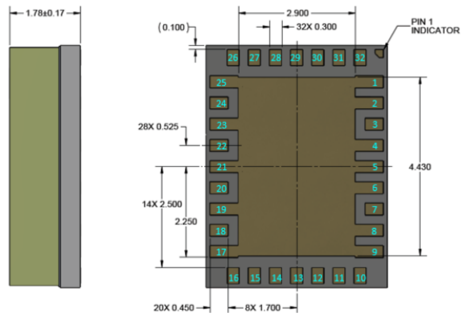
Table 1. Published Ka-Band Benchmarks.

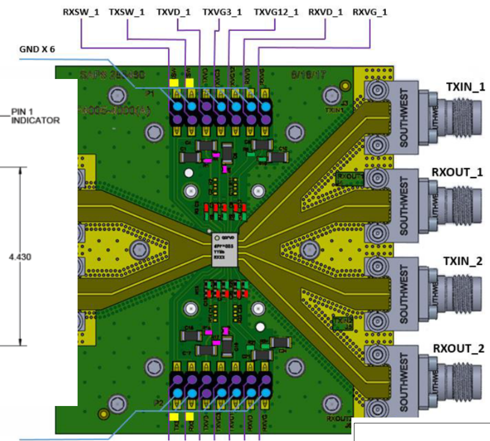
"High Efficiency Ka-Band Gallium Nitride Power Amplifier MMICs," IEEE COMCAS 2013

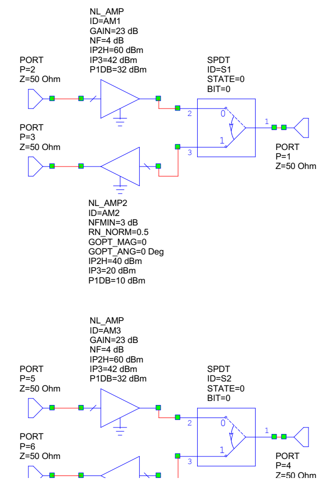
"A highly integrated RF frontend module including Doherty PA, LNA and switch for high SHF wide-band massive MIMO in 5G," PAWR '17

GaN FEM



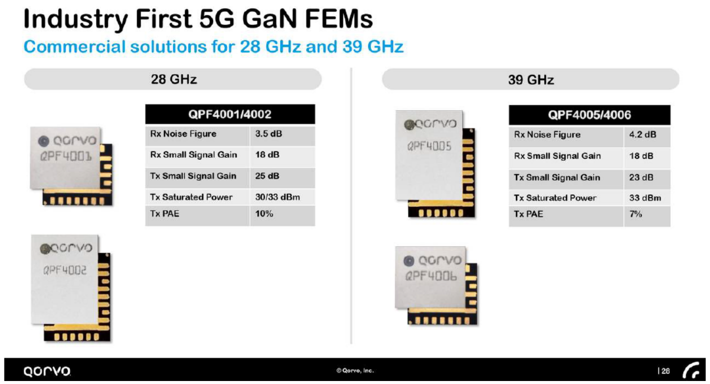






Product Features

- Frequency Range: 37 – 40.5 GHz [1]
- RX Noise Figure: 4.2 dB
- RX Small Signal Gain: 18 dB
- RX Saturated Power: 17 dBm
- RX TOI : 20 dBm @ - 5 dBm Pin / tone
- TX Small Signal Gain: 23 dB
- TX Saturated Power: 33 dBm
- TX TOI: 42 dBm @ 24 dBm Pout / tone
- TX ACPR: 32dBc @ 24dBm average Pout [2]
- TX Linearity: 4% EVM @ 24 dBm average Pout [2]
- TX PAE: 7% @ 24 dBm average Pout.
- Package Dimensions: 4.5 x 6.0 x 1.8 mm



Industry First 5G GaN FEMs

Commercial solutions for 28 GHz and 39 GHz

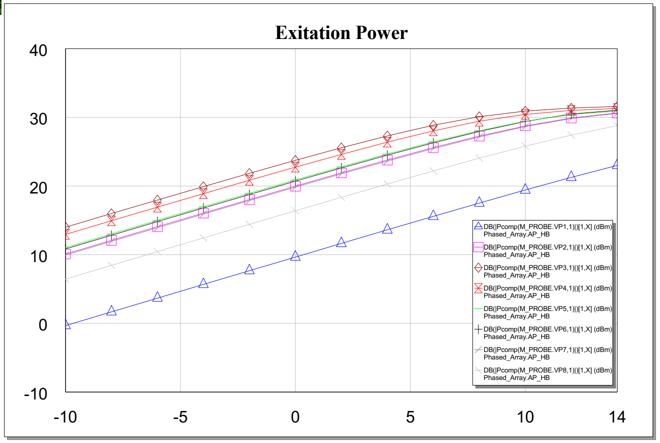
28 GHz

QPF4001/4002	
Rx Noise Figure	3.5 dB
Rx Small Signal Gain	18 dB
Tx Small Signal Gain	25 dB
Tx Saturated Power	30/33 dBm
Tx PAE	10%

39 GHz

QPF4005/4006	
Rx Noise Figure	4.2 dB
Rx Small Signal Gain	18 dB
Tx Small Signal Gain	23 dB
Tx Saturated Power	33 dBm
Tx PAE	7%

QPF4005 Datasheet Qorvo



ni.com/awr

3D Glass BPF

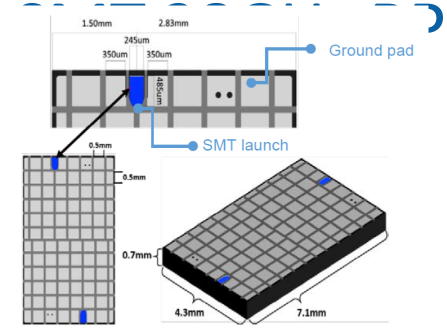
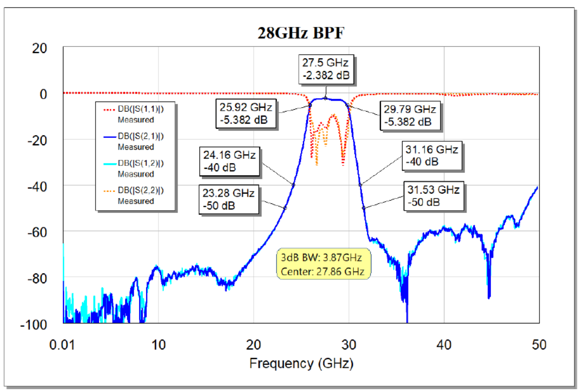
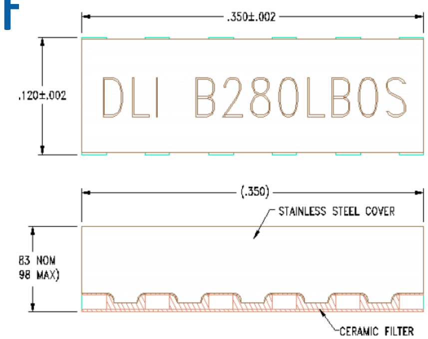


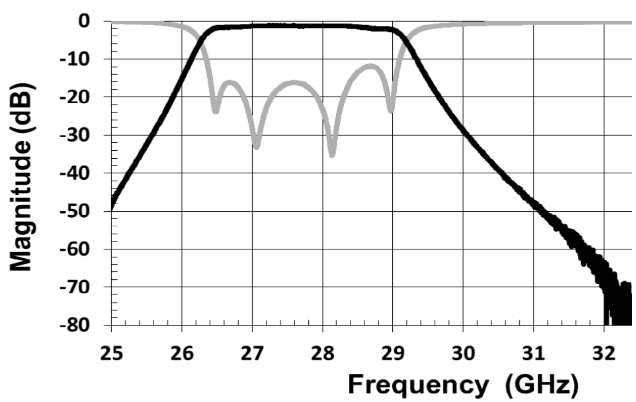
Figure 3. Dimensions and details for SMT launch and ground pads.



From https://www.3dglasssolutions.com/

DLI B280LB0S

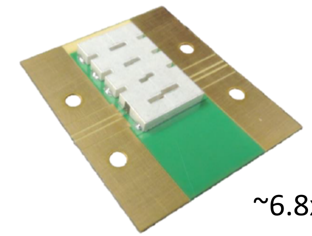




B280LB0S Datasheet DLI

Murata Quartz WG BPF

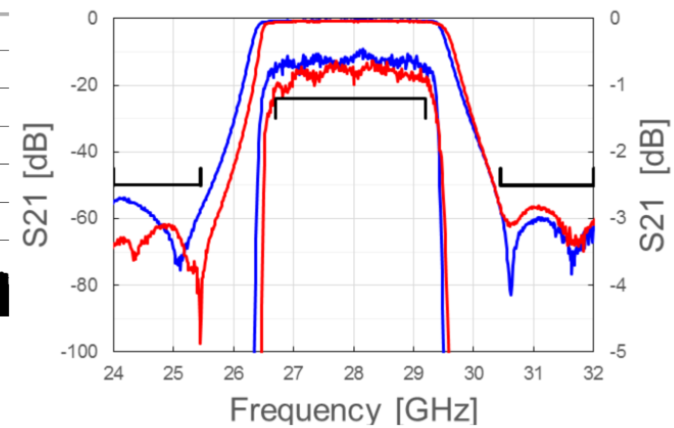
Quartz covered with silver



~6.8x17x1.5mm^3

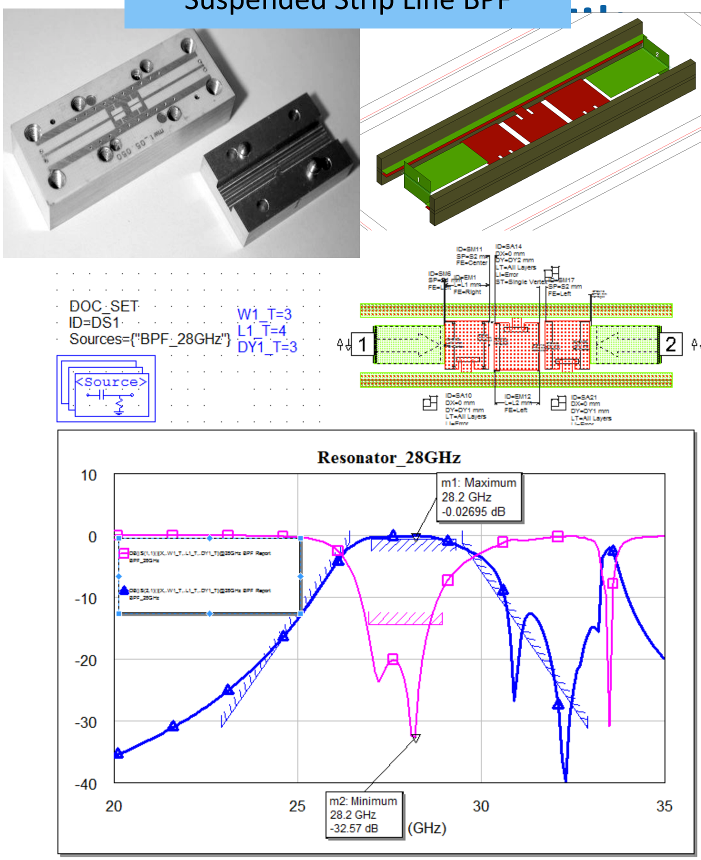
Print circuit board (RO4350B)

(ε_r =3.66, tan δ =0.004, t=0.256mm)

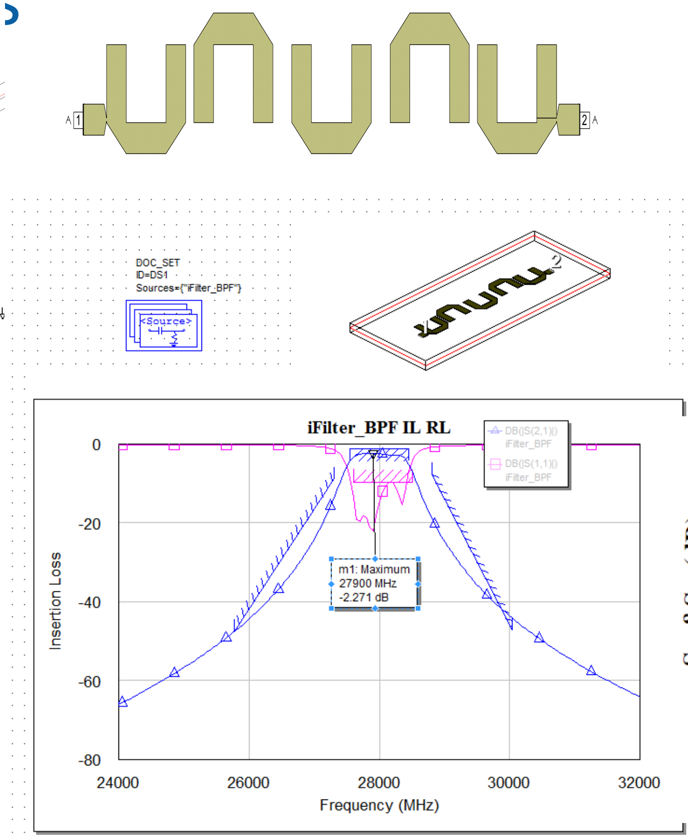


“A Compact 28GHz Band Pass Filter using Quartz Folded Waveguide,” IMS2018

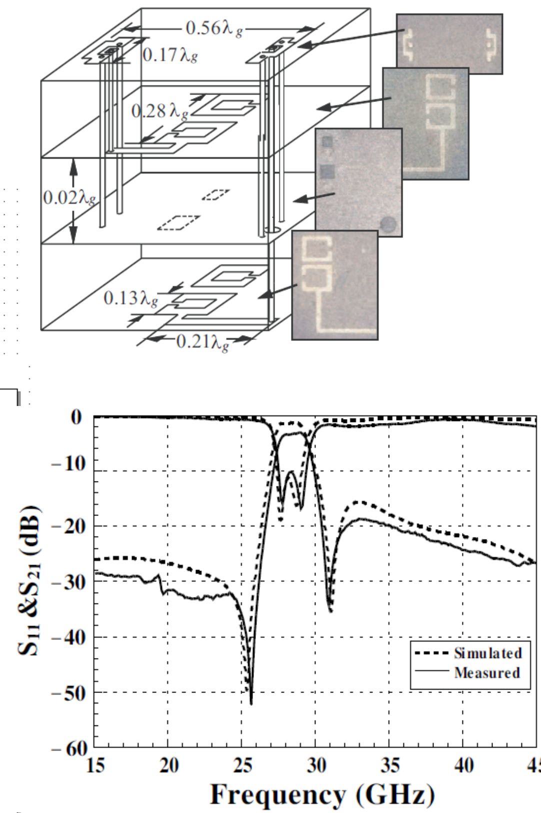
Suspended Strip Line BPF



Strip Line BPF

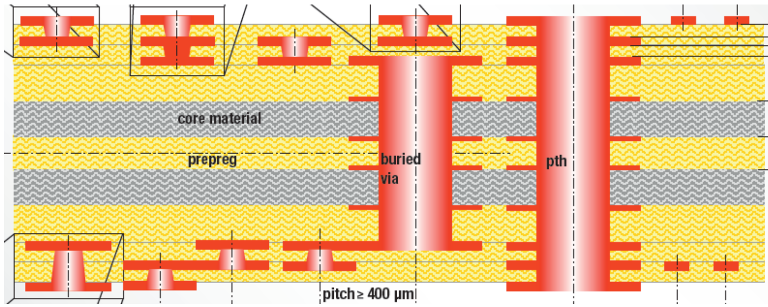


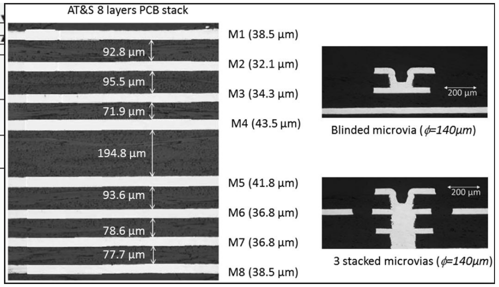
LTCC BPF

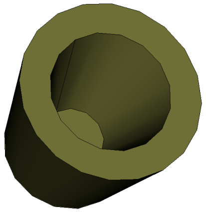


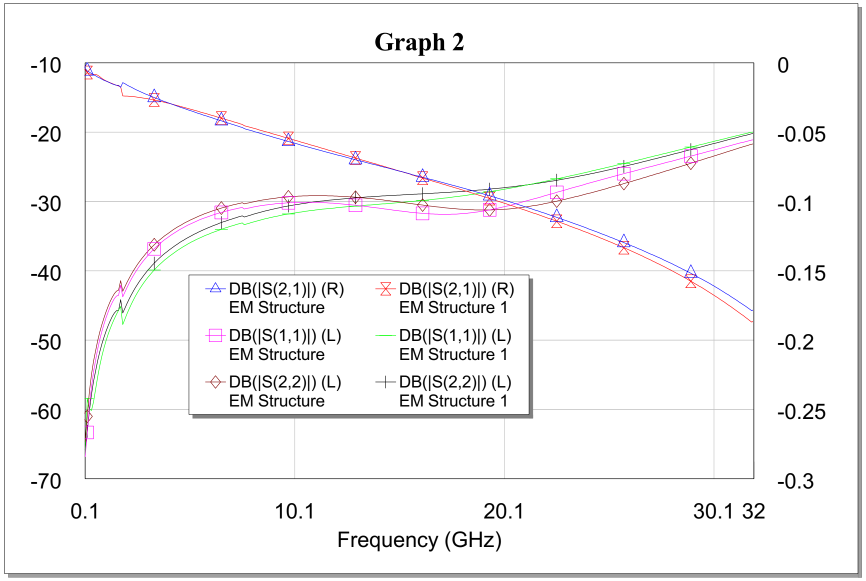
"LTCC VERTICALLY-STACKED CROSS-COUPLED BAND- PASS FILTER FOR LMDS BAND APPLICATIONS," *Progress In Electromagnetics Research C 2011*

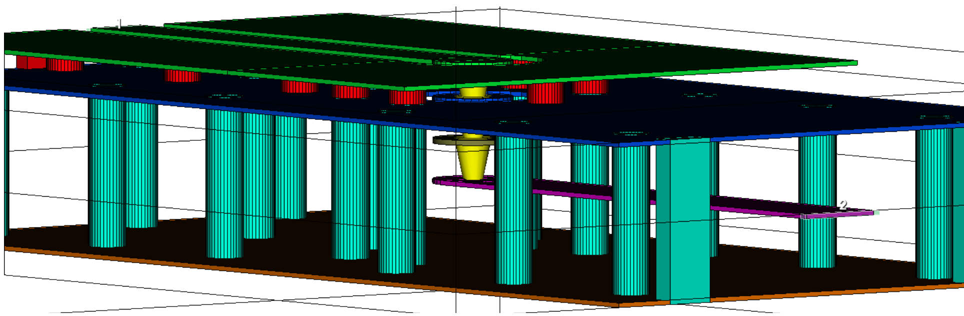
Microvia and PTH





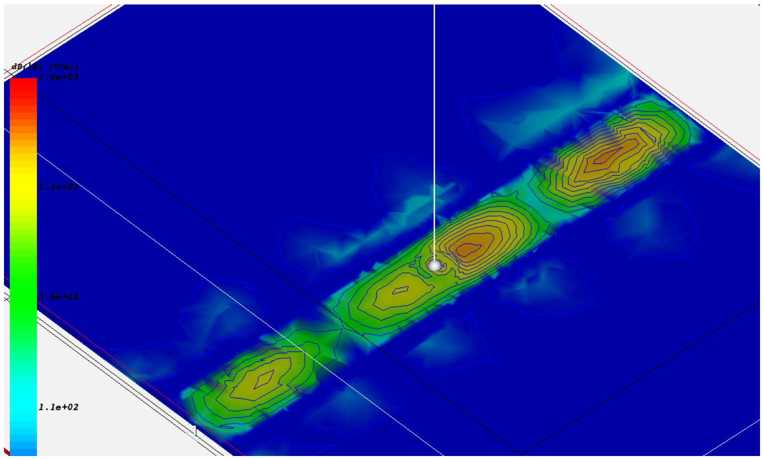


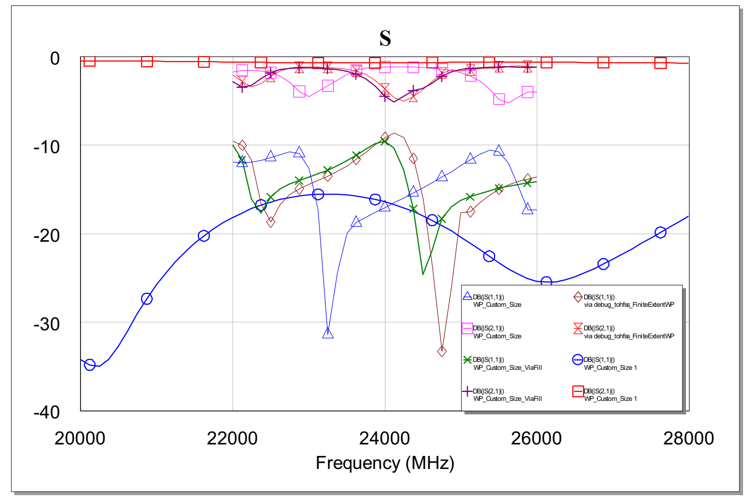


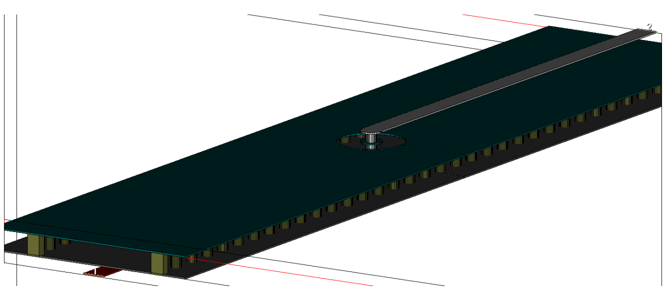


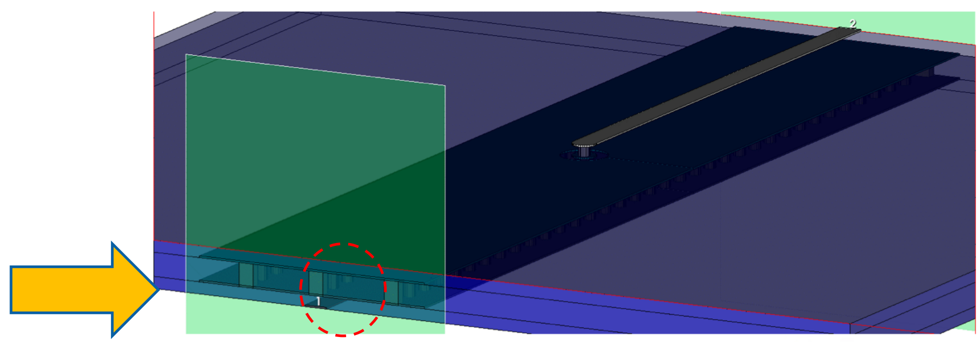
From the websites of Würth Elektronik and AT&S

Suppress Spurious Wave Modes

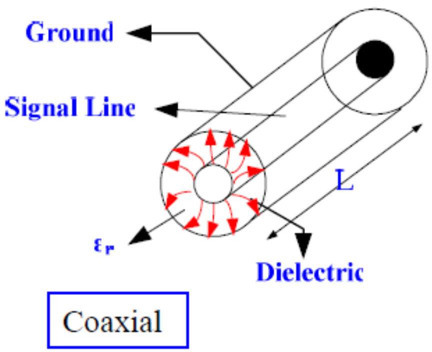


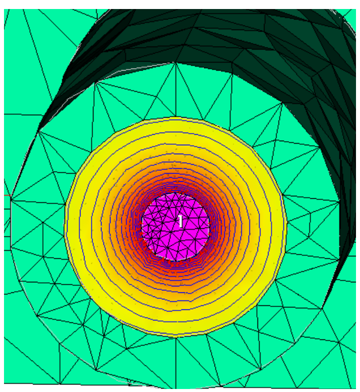


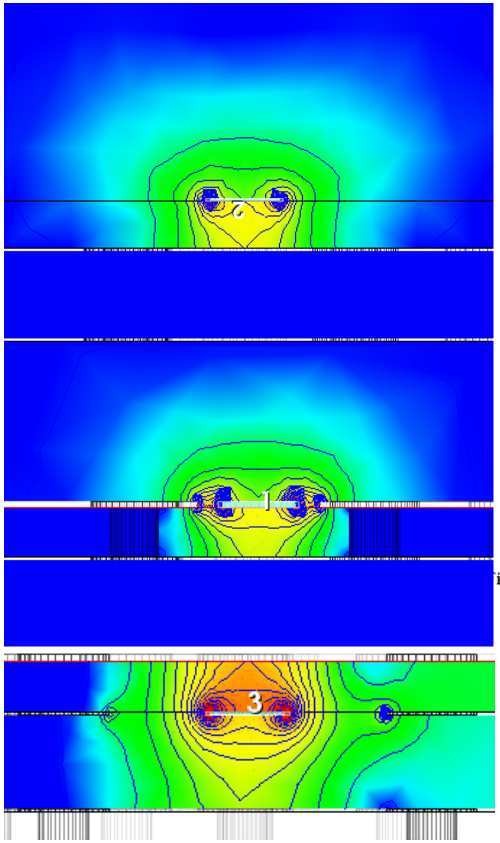


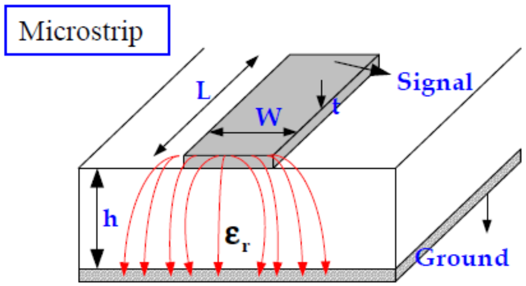


E field of mmWave Transmission Lines

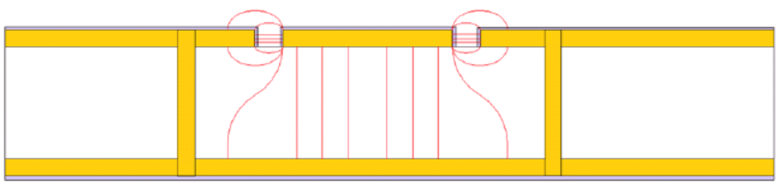




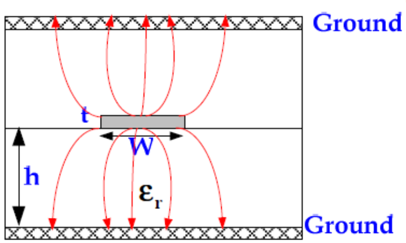




"Transmission Line Geometries", T. Weller, Univ. of South Florida



igure 9. This diagram illustrates how the electric fields of a GCPW circuit use four layers of ENIG plated finish,



Ref: "The Effects of PCB Fabrication on High-Frequency Electrical Performance", www.Rogers.com

mmWave Circuit Design Challenge

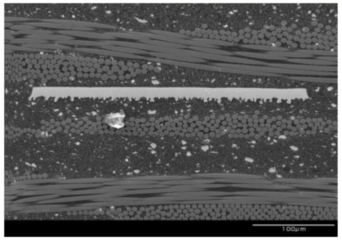
- **Loss on Board:**
  - Conductor Loss (resistive, skin effect, roughness)
  - Dielectric Loss (loss tangent)
  - Radiation Loss (proportional L/λ)

Frequency	FR4 Copper Loss	FR4 Dielectric Loss	FR4 Total Loss	4350 Copper Loss	4350 Dielectric Loss	4350 Total Loss
10 MHz	0.005	0.001	0.006	0.005	0.000	0.005
100 MHz	0.019	0.012	0.031	0.019	0.002	0.021
1 GHz	0.090	0.123	0.213	0.090	0.017	0.107
10 GHz	0.330	1.227	1.557	0.330	0.173	0.503

FR4 dielectric loss exceeds copper loss at 1 GHz

Frequency (GHz)	Skin Depth in Copper (um)	Microstrip Wavelength (Er=3.66) (mm)
1	2.00	179
10	0.67	17.7
30	0.38	5.73
40	0.33	4.53
77	0.24	2.36

"Overview and Comparison of Microwave PCB Transmission Line Circuits" Rogers, PCB West 2012
"Wideband characterization of printed circuit board materials up to 50 GHz", Aleksei Rakov



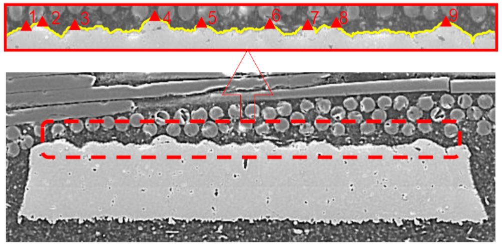


Figure 3.24 An example of the validation of automatically detected peaks

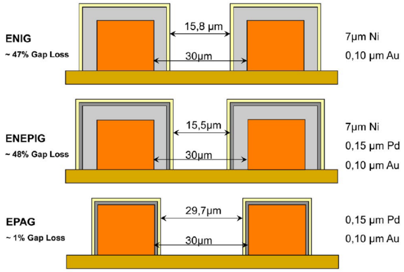
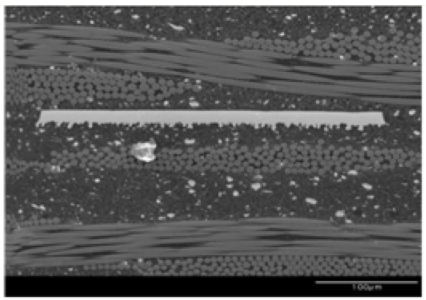
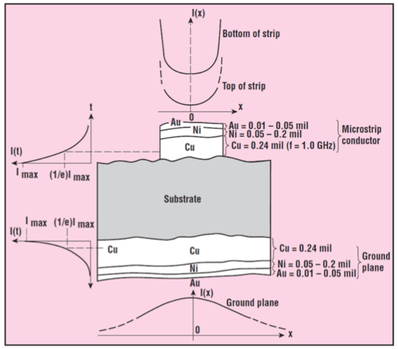


Figure 2: The impact of established Ni containing finishes on line and space.

"The Future of Nickel in Nickel/Palladium/Gold Final Finishes",PCB Design Magazine April 2015

Finishes and Roughness of Metal





7. This cross-sectional view shows the current distribution across a microstrip conductor and its ground plane.

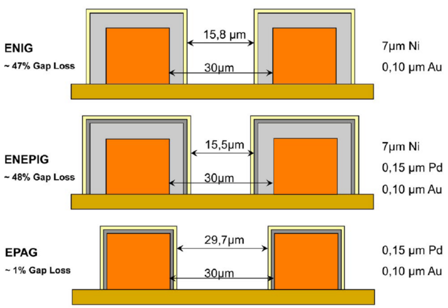
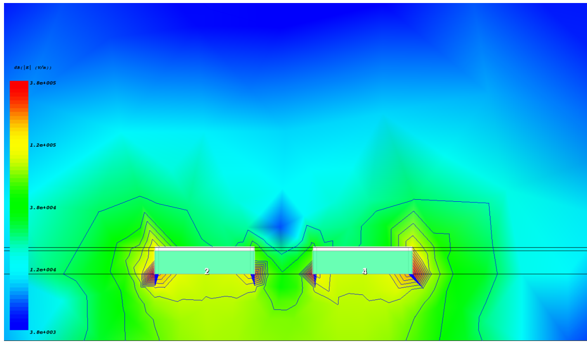


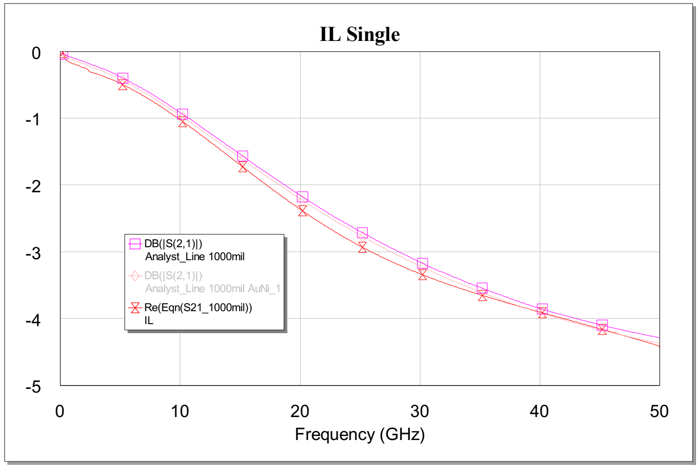
Figure 2: The impact of established Ni containing finishes on line and space.

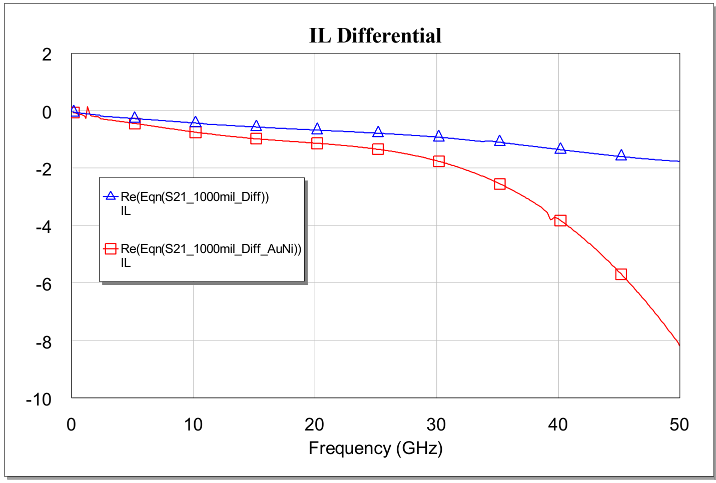


Enclosure | Material Defs. | Dielectric Layers | Materials | EM Layer Mapping | Line

Material properties for conductors, vias, etc... (thickness specified in mil)

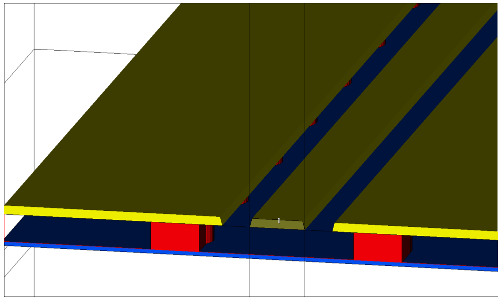
Name	Thickness	Material Defi...	Etch Angle	Roughness
Perfect Conducto	1.4	Perfect Conducto	0	0
1oz	1.22	Copper	0	0.0236

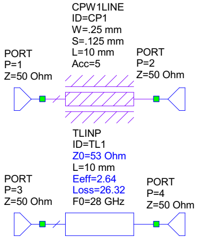


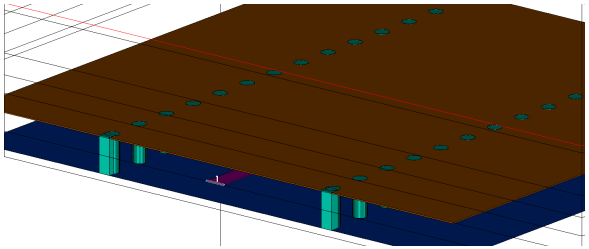


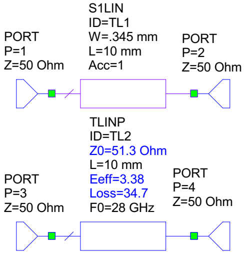
Ref: “Reviewing The Basics Of Microstrip Lines”, MICROWAVES & RF n MARCH 2000

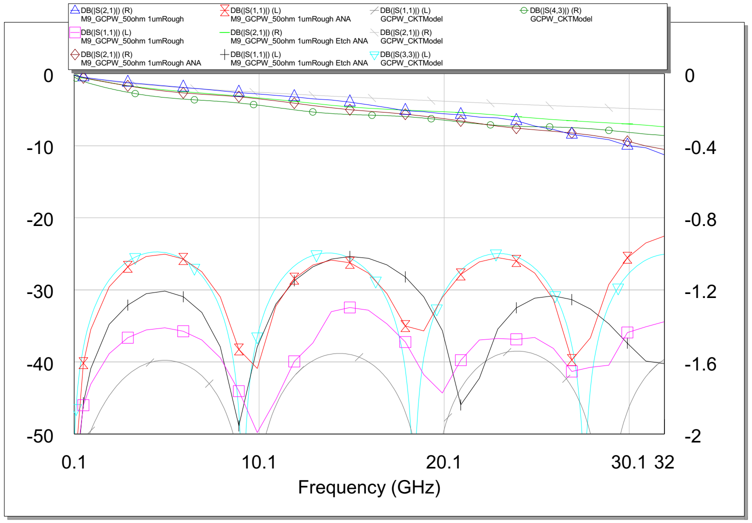
Roughness and Etching Studying for Strip Line and GCPW

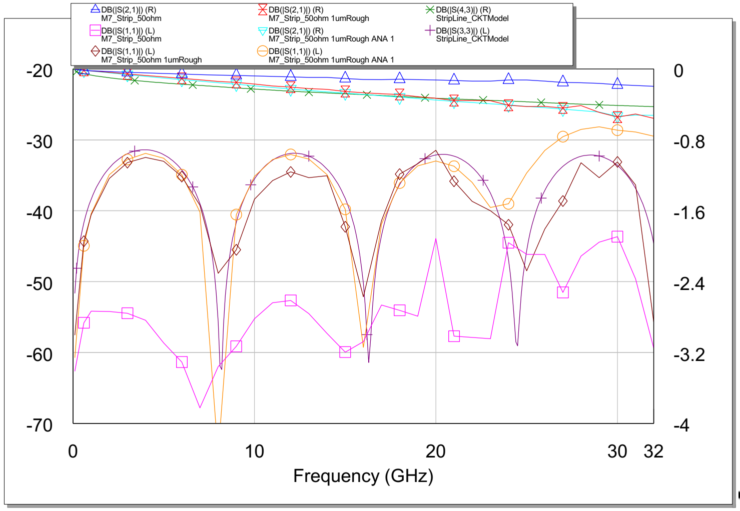






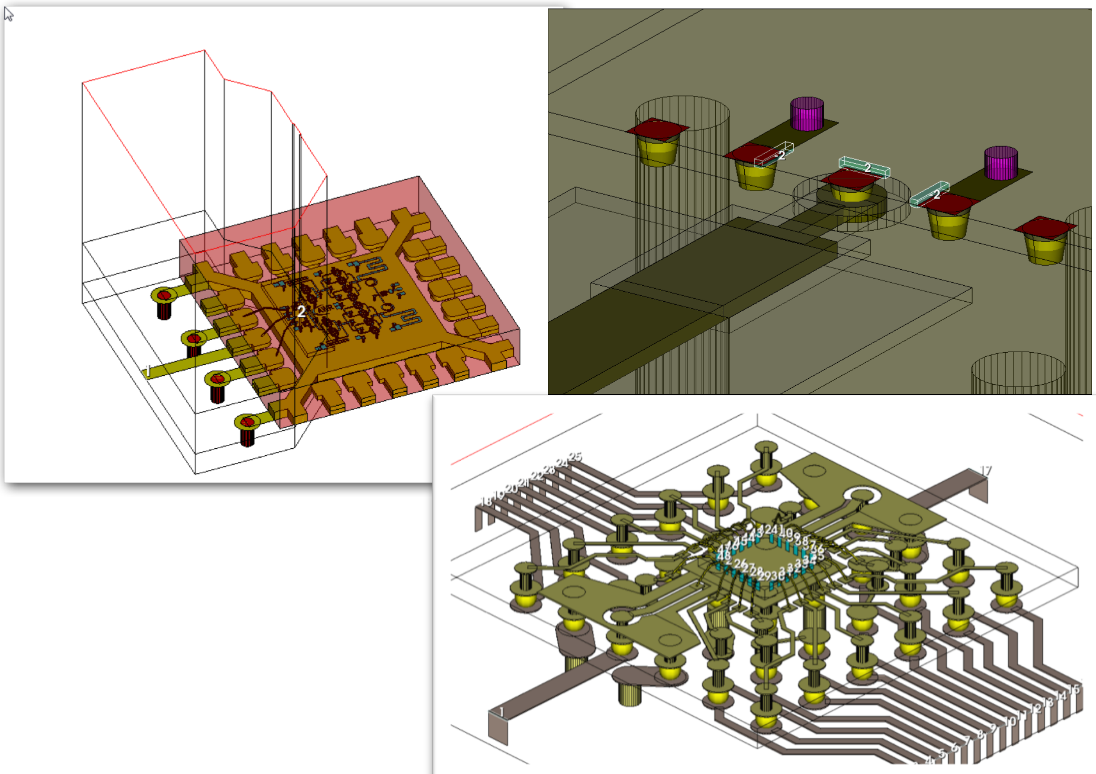






RFIC/MMIC in QFN/Flip-chip/Wire-bonding Package on PCB Board

We are interested in the launch from the board into the package by means of bond wires/flip-chip and including the quad flat no lead (QFN) package or IC carrier board/module



	SnPb C4 Bump	Pb-Free C4 Bump	Cu Pillar + Pb-free Cap	Cu µ-Pillar + Pb-free Cap
Structure		SnAg	SnAg Cu	SnAg Cu
Diameter	75 – 200 µm	75 – 150 µm	50 – 100 µm	10 – 30 µm

Electromigration

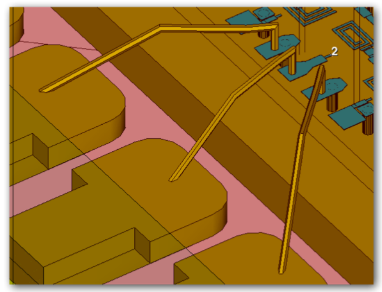
Interesting questions are:

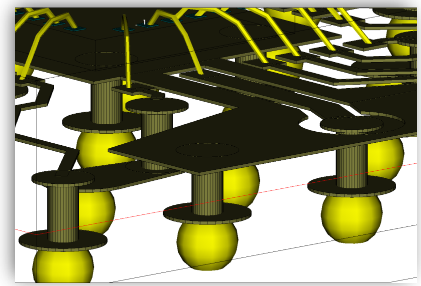
- Performance of launch
- Ground studies
- Package resonances
- Optimization of layout
- Yield analysis

NATIONAL INSTRUMENTS

3D Cells and PDK (Library) Cells (Analyst)

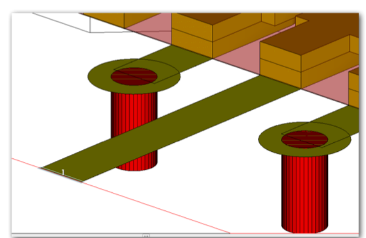
- 3D Cells are predefined, parameter controlled cells, for common types of 3D objects:
  - Bond wires
  - BGA balls
  - QFN packages
  - SMA connectors
  - Custom cells



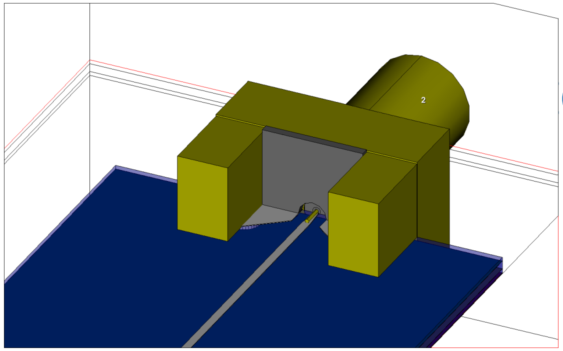


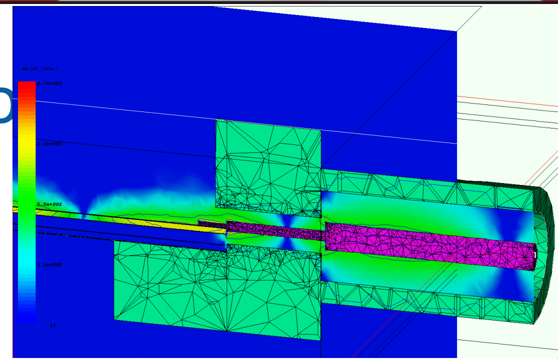
The simulator needs to support the cell

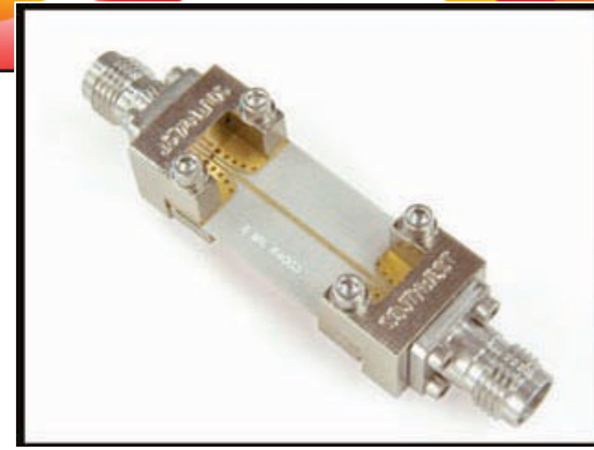
- Library cells are part of the PDK for the technology. Their layout can be used for
  - Vias
  - Multi-metal layer lines
  - Spirals

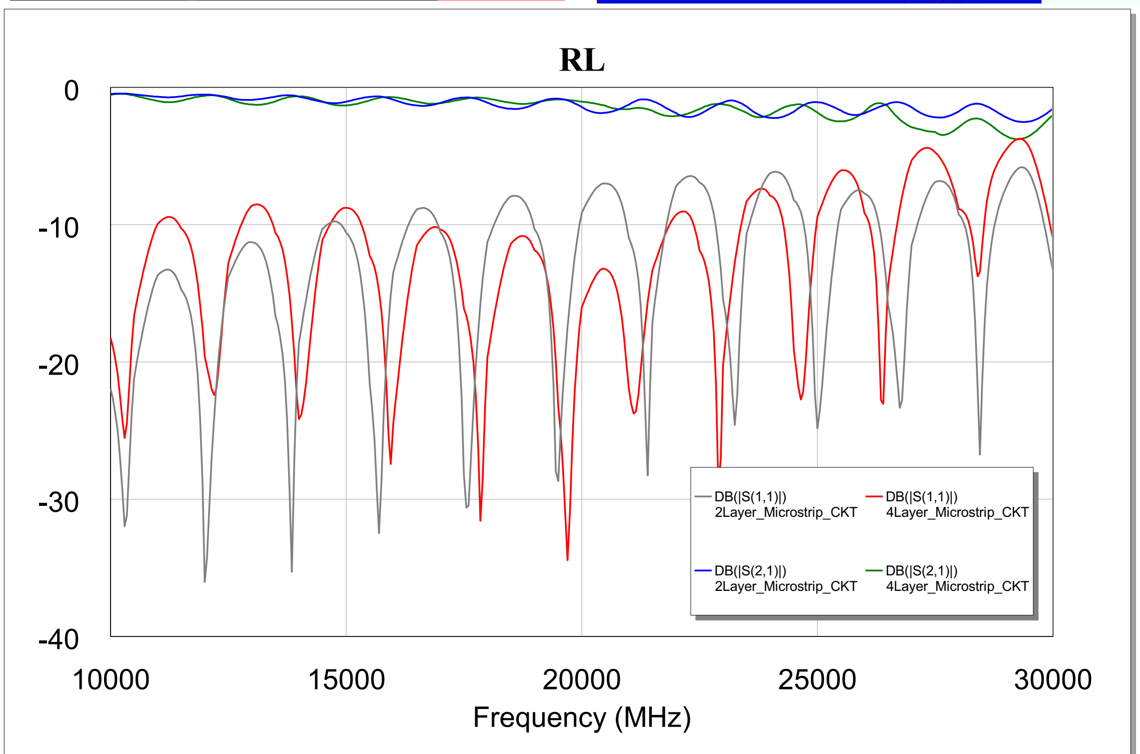


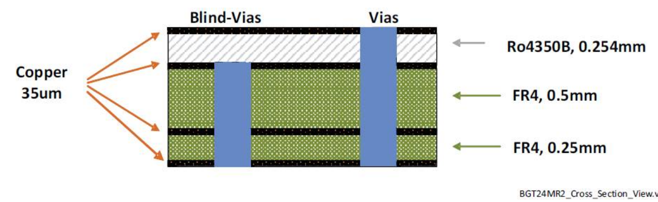
Grounding vias from the board PDK







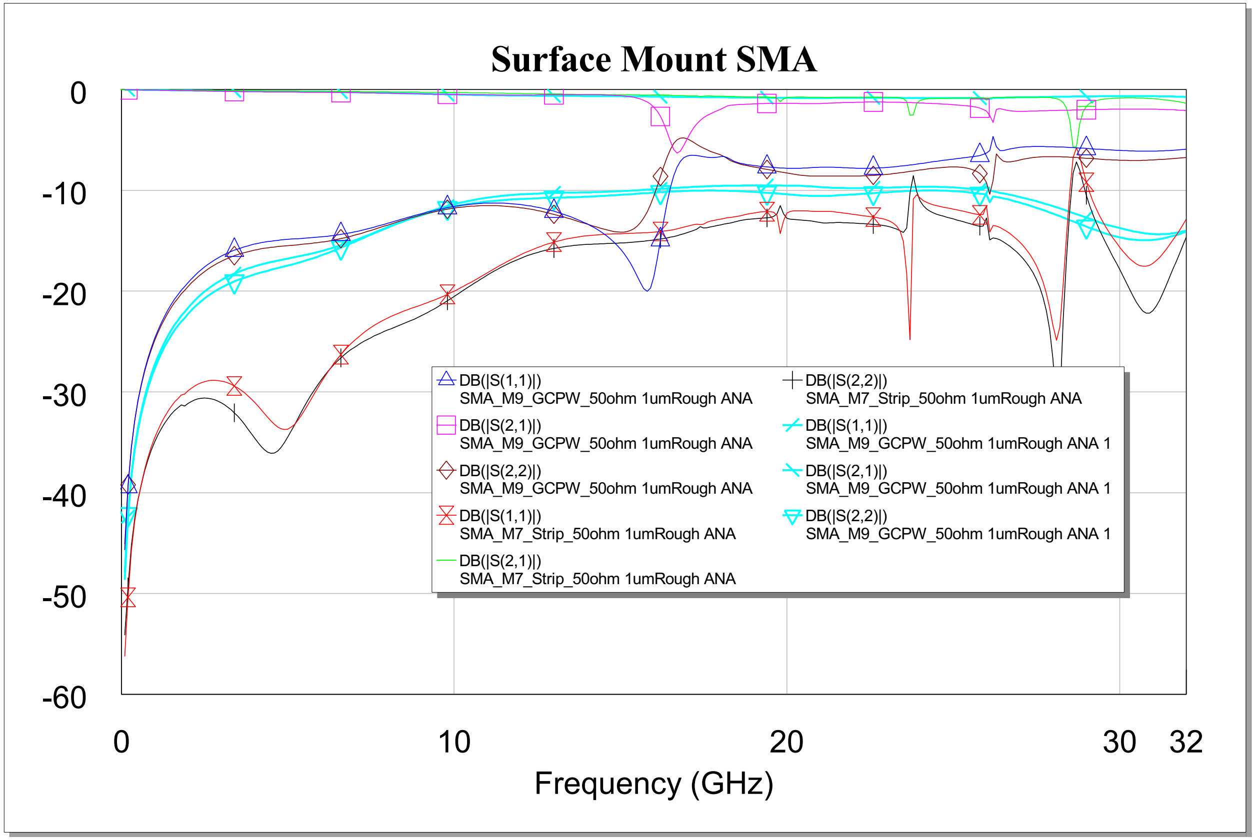


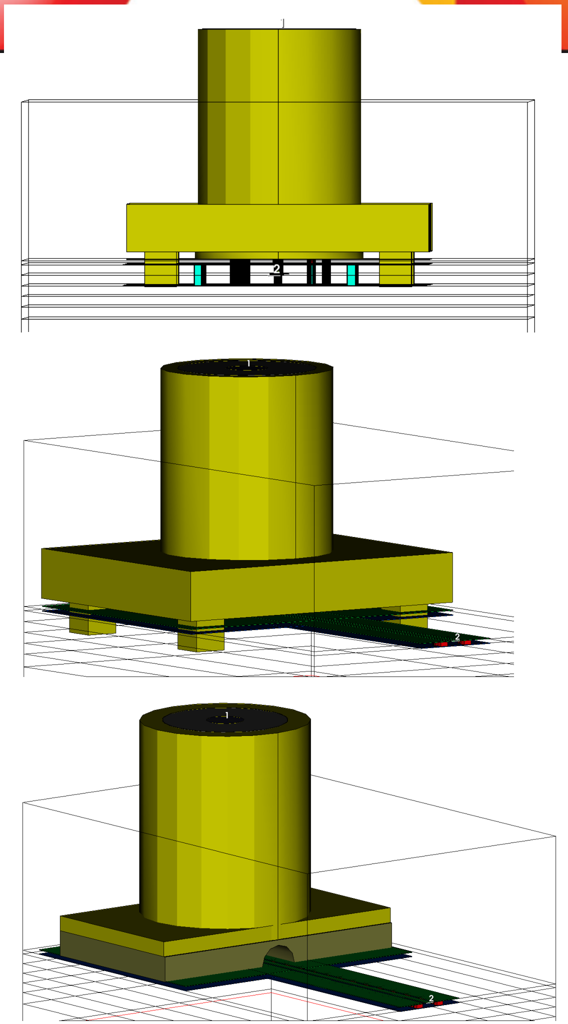


Frequency (GHz)	Skin Depth in Copper (um)	Microstrip Wavelength (Er=3.66) (mm)
1	2.00	179
10	0.67	17.7
30	0.38	5.73
40	0.33	4.53
77	0.24	2.36

NATIONAL INSTRUMENTS

Surface Mount SMA to SL and ML





Additional Information (Knowledge Base)

- Many useful articles, scripts, and extra examples can be found within the NI AWR software Resource Library: awrcorp.com/resource-library
- AWR website: www.awrcorp.com/
- E-Learning portal: awrcorp.com/awr-support/training-center/e-learning-portal
- AWR-TV YouTube video channel: awrcorp.com/awrtv-player